

Scientific Applications of Current Diving Technology on the U.S. Continental Shelf

Results of a Symposium Sponsored by the National Undersea Research Program, University of Connecticut at Avery Point, Groton, Connecticut, May 1984

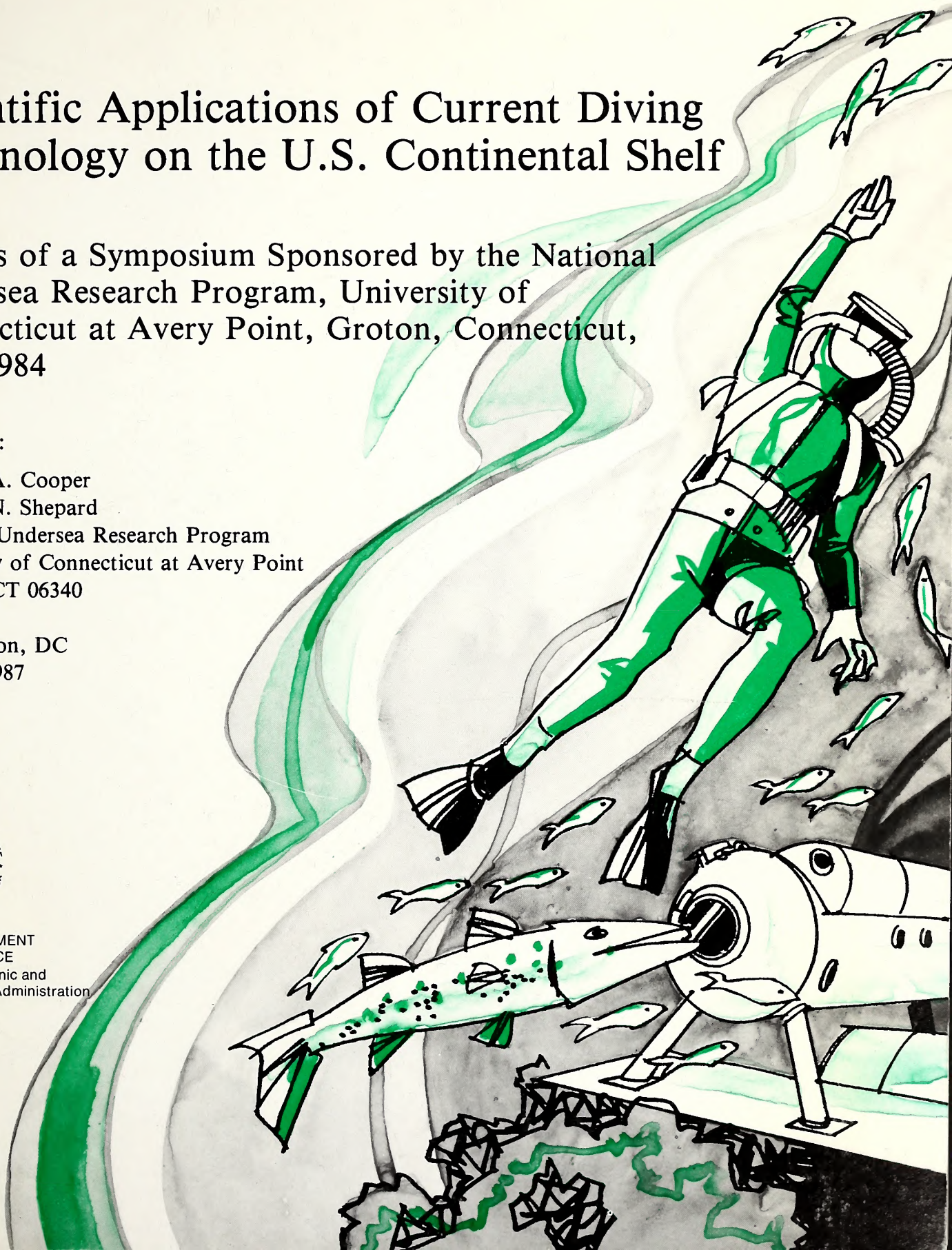
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Scientific Applications of Current Diving Technology on the U.S. Continental Shelf



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CHAPTER I. INTRODUCTION

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This volume contains nineteen undersea research and technology papers that summarize the current status of U.S. continental shelf research supported by NOAA's Office of Undersea Research during the late 1970's and early 1980's. Principal investigators gave presentations on these research activities during a NOAA -University of Connecticut sponsored symposium, May 22-24, 1984 with abstracts published in NOAA's Symposia Series for Undersea Research, Vol. 2, No.1, 1984. Participants in the 1984 symposium were comprised of scientists (biologists, geologists, chemists, physical oceanographers and archaeologists), operations specialists, and program managers from all the regions of the U.S.

Also included in this volume is a definition of the science objectives and research themes of NOAA's National Undersea Research Program, University of Connecticut, as discussed during the 1984 symposium and subsequently refined through numerous discussions with our northeast region scientists and coordinators from New England, southern New England, and the Great Lakes. These science objectives are to be re-examined in 1988 and re-defined in the context of major research themes pertaining to each of the three geographic regions for which the University of Connecticut's program is responsible.

An overview of the papers presented herein clearly indicates that NOAA supported underwater research conducted from manned submersibles, and with SCUBA, is in a transitional phase. During the 1960's and early 1970's "submersible science" was primarily a qualitatively descriptive activity with participants mainly concerned with observing and photographically documenting the ecology of one or several species, animal-substrate relationships, behavior of fishing and research sampling gear, physical and biological characteristics of water column fauna, surficial geology of selected environments, and the relationships of bottom currents to the sediment-water interface and geological features. In situ sampling in a replicated fashion and site revisitation was difficult to achieve, if even attempted, given the relatively ineffective science support capabilities of manned submersibles that had been designed and outfitted to address commercial "oil field" type tasks.

The research papers presented in this volume reflect this transition from a purely descriptive (qualitative) science to one that is beginning to quantitatively define, through calibrated sampling and sensing hardware and replication, the various phenomena and ecological relationships that currently are the focus of much of our underwater research attention.

For example, submersible based studies of tilefish populations, their habitats, and bioerosion by tilefish were conducted by Grimes et al. in the Middle Atlantic - southern New England region. Horizontal excavations in clay outcrops in the walls of submarine canyons, scour depressions under rocks and boulders and vertical, funnel-shaped burrows in compacted clay substrata are the primary habitats occupied by tilefish. The abundance and dimensions of these shelters are defined from Lydonia, Veatch, and Hudson Canyons. Relatively warm stable temperatures ($9-14^{\circ}\text{C}$) and the availability of maleable substrates for burrowing appear to be the major environmental factors critical to establishing the burrow and excavation shelters. Also, the rate and net effect of bioerosion as an active erosional process on the Continental Shelf and Slope was measured around the head of Hudson Canyon. Tilefish as large as 30 kg construct funnel-shaped burrows as much as 5 m in diameter and 2 m deep. Sidescan-sonar images show that the burrowed area corresponds closely to an 800 km area of large irregularly spaced hummocks 1-10 m high. The abundance of tilefish burrows and their clustered distribution has led Grimes et al. to hypothesize that the activity of tilefish during the Holocene may have created the hummocky topography.

Fishing behavior of halibut longline gear and the effectiveness of various types of bait and hooks were quantitatively assessed by High using submersibles in coastal waters of Alaska. Several bait types were tested for durability on traditional "J" type hooks and newly introduced "circle" type hooks in addition to defining escape rates as a function of hook type. Half the halibut were hooked within the first two hours of soak, and less than 10% of the catch were hooked after six hours of soak, due to the rapid rate of bait loss. Circle hooks were far superior to traditional hooks, permitting fewer fish to escape; they captured 60% more halibut, 130% more rockfish, and 100% more miscellaneous species.

A five-year benchmark (baseline) of species abundance, community structure, habitat associations and contaminant (heavy metals, petrogenic hydrocarbons and PCB's) loads (surficial sediments, scallops, lobsters, jonah crabs and tilefish) was defined by Cooper et al. at site specific study locations on Georges Bank and in several of the Georges Bank submarine canyons. Two years of quantitative data collections prior to drilling for gas and oil and three years after the onset of drilling have demonstrated no measureable impacts to the megabenthic fauna or their habitats, thus, a five-year data base exists against which to judge future drilling activities on Georges Bank or within the submarine canyons, which seem likely by the Canadians during the 1990's.

Simmons and Love, in the process of studying the ecology of deep water benthic algal mats in the Key Largo Marine Sanctuary with submersibles made the first detection and water quality measurements of submarine ground water discharge (SGWD) into a deep coral reef habitat. The importance of the water quality to perturbation of deep coral reef habitats and contributions to sea floor processes is very significant. SGWD was measured in-situ

with seepage meters yielding flow rates of 3 l/hr. and 40 ml/hr. Oxygen levels ranged from 0.30 to 2.32 mg/l. Numerous pesticide peaks and heavy metal concentrations 100-10,000 times mean sea water values were measured. These results suggest a high potential for perturbation of benthic fauna.

Dillon et al., using the deep diving submersible Alvin, conducted three transects along the exposed face of the Blake Escarpment, east of Florida at depths of 1400 to 4000 m. Outcrops of horizontal strata known to extend westward beneath the Blake Plateau were sampled. The vertical limestone cliff at the northern end of the escarpment is maintained by erosion and corrosion. To the south, broad slopes of rippled pteropod sand lie between nearly vertical outcrops. The presence of a Mesozoic reef is indicated. The escarpment's present configuration resulted from kilometers of subsidence and kilometers of erosional retreat.

Valentine, using submersibles on the outer shelf, in a submarine canyon head, and on the gullied upper slope indicates that sediment dynamics differ markedly in adjacent areas at the same water depth (150-600 m) on the southern flanks of Georges Bank. Strong tidal currents directed north and south dominate flow up and down the canyon axis to 600 m. In contrast, tidal currents on the upper slope are weak, and intermittent currents related to Gulf Stream eddies flow eastward along the slope above 300 m. Major sea-floor processes in the energetic canyon head are erosion and transport, whereas deposition is more likely in the same depth interval on the more tranquil upper slope.

The above examples are representative of the transition that NOAA supported undersea research is currently going through. Research conducted under the auspices of the University of Connecticut's Undersea Research Program during 1985 through 1987 is strongly geared towards quantitative, experimental, process oriented studies that require site revisitation on an annual, if not seasonal, basis. There will always be a need for purely descriptive studies, especially in those areas that have received relatively little attention to date. A blend of descriptive and experimental process oriented research is the goal of the Connecticut program.

Special thanks are due the reviewers who contributed valuable time to these proceedings. We thank Marcia Collie, Staff Assistant in NOAA's Office of Undersea Research (OUR), for her expert editorial assistance in the final preparation of this document. NOAA's OUR provided support for the publication. Constance Fontaine, Jeanie Klemm, Hannah Goodale, and Sheryl Windsor patiently typed and edited the numerous drafts. Lastly, we would like to express our appreciation to the authors for their patience and cooperation during the extended time required to complete this document.



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THE EFFECTS OF HUMAN ACTIVITY ON THE
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Chapter II
Fisheries
The National Academy of Sciences
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CHAPTER II

FISHERIES

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THE EFFECT OF CURRENT SPEED ON THE SMALL SCALE SPATIAL
DISTRIBUTION OF FISHES

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ABSTRACT

Observations during the course of over 600 dives (0.5 to 33 m depth) by biologist-divers at current dominated sites off southern New England revealed that changing current velocity is a factor limiting and shifting the small scale spatial distribution of certain fish species by size class. Fluctuating current speeds changed the size class composition of each species that foraged on surfaces exposed to current or in the water column. Current exposed areas represent continuously varying refuges for planktonic, epifaunal and infaunal prey; such refuges are available to size classes of fish which can maneuver under existing current conditions. Shifts in distribution continuously changed the search area for prey, hence predation by particular size classes changed throughout each tidal stage. Physical and behavioral isolating mechanisms were discerned that may allow fishes to utilize the same prey resources while reducing instances of direct competition. I suggest that cyclic changes in tidal current velocity may act on fish communities in a manner similar to the way physical disturbance and predation act on other communities in mediating coexistence. Disturbance mechanisms may be important mediating factors contributing to the maintenance of species diversity in temperate marine fish communities where species exhibit high degrees of prey overlap at the intraspecific and interspecific level.

INTRODUCTION

Studies of food habits and spatial resource partitioning in marine fish communities have appeared with greater frequency in the recent literature (Tyler, 1972; Smith and Tyler, 1972; Hobson and Chess, 1976; Langton and Bowman, 1980; Hacunda, 1981; and others). These studies reflect a broader ecological interest of how species coexist. Resource utilization, such as how prey species are partitioned by sympatric predatory species, has been studied to determine community dynamics and develop hypotheses about community structure in general (Schoener, 1974).

Langton and Bowman (1980) and Hacunda (1981) found high degrees of food overlap in studies of fish communities in the northwest Atlantic. Percent similarity and overlap indices ranged as high as 0.75, indicating significant overlap in prey species utilization by a variety of predators. For species to coexist and minimize inter and intraspecific competition, slight differences in the foraging behavior of predators have been proposed, including feeding on different sizes of prey, feeding at different times, or in different areas (Smith and Tyler, 1972; Tyler, 1972; Ross, 1977; Werner, 1977; Jones, 1978; Keast, 1978).

This line of reasoning implies a mechanism would be needed that isolates one species from another, or one size class from another, resulting in a reduction of direct competition for specific prey resources. For example, Smith and Tyler (1972) described space resource sharing in a coral reef fish assemblage and interpreted the species specific behavior patterns as a mechanism to reduce competition.

In this paper, I hypothesize that current velocity constrains the small scale distribution of temperate marine reef fishes. I present observational data to support this hypothesis, discuss how this process might reduce competition for prey resources, and apply these assumptions to other temperate, demersal fish communities.

The hypothesis states that as current velocity increases or decreases over the substrate, the small scale distribution of size classes of different species contracts or expands respectively. This process changes the size class composition of each species that can forage in particular places in the water column or on current exposed surfaces. Shifts in distribution continuously change the search area, hence predation by particular size classes changes throughout each tidal stage. This size class isolating mechanism would allow different fish predators to share the same prey resources on a small scale and reduce instances of direct competition.

METHODS AND STUDY AREA

Direct underwater observations were made of common fish species at temperate rocky reefs in southern New England between 1979 and 1983. Observational data consisted of immediate post-dive debriefing of species-specific and interactive behaviors and underwater photodocumentation of selected behavioral phenomena. This data set from over 600 dives between 0.5 and 33 meters depths has allowed me to develop a general chronology of activity at these reef sites. Observations were made at many sites throughout New England, but primarily at Latimer Reef and Ellis Reef in Fishers Island Sound, off Wreck Island on the south shore of Fishers Island, and off Bull Point on Conanicut Island in Narragansett Bay, Rhode Island. Dives were made at all stages of the tidal cycle.

OBSERVATIONS

Cunner, Tautogolabrus adspereus, typically aggregated at various heights of rocky reefs in loose foraging groups. Individuals were often seen preying on planktonic, epibenthic or infaunal species in a common scan and pick feeding mode (sensu Keenleyside, 1979).

Observations of cunner aggregations, during various tidal stages and in areas of significant tidal current velocity (the velocity which begins to limit maneuverability), demonstrated distinct changes in height (see Table 1 and Figure 1 for example) and distribution by size class of fish above and on the bottom. Larger fish foraged further from the reef substrate and on current exposed surfaces for longer periods of time. As current velocity

over the reef decreased, smaller size classes of cunner swam up into the water column and out onto current exposed surfaces in search of prey. In some areas, even young of the year individuals foraged in reef sections previously exposed to currents. As current speeds increased the process reversed itself.

For example, data from one observation period (Table 2a) show distinct changes in size class composition over a current exposed surface during part of a tidal cycle. A two-way analysis of variance (Table 2b) shows that the interaction of both current speed and size class of individuals have significant effects on the number of fish foraging on current exposed surfaces. Figure 2 is a schematic representation of the situation on a typical reef.

Individuals swimming into the fast current region generally traveled in the downcurrent direction. Observations at the downcurrent edge of Ellis Reef indicated that generally no animals were lost from the reef at high current speeds. Since all size classes occurred at the upcurrent edge of the reef at high current speeds, it would seem that movement of the respective size classes within the reef system is downcurrent above the reef and through the reef infrastructure, but upcurrent only through the reef infrastructure (Figure 3). Individuals were occasionally followed which demonstrated this complete behavioral sequence.

Feeding was observed during all stages of the tidal cycle. Even at high current velocities, when no fish were above the reef or on surfaces exposed to current, individuals were observed within crevices and in low current areas of the reef continuing their scan and pick feeding.

Other sympatric reef fish species were also observed to be current-limited in the extent of their foraging area. Rock eel, Pholis gunnellus, radiated shanny, Ulvaria subbifurcata, and grubby sculpin, Myoxocephalus aeneus, were all limited by size class to areas of the reefs where they could effectively search for prey. All three species were limited to low current areas of the reef during high current periods, with some individuals searching at current-exposed surfaces or over adjacent sand plains at slower current speeds.

Semi-demersal migratory schooling species such as scup, Stenotomus chrysops, and pelagic schooling species such as the Atlantic silverside, Menidia menidia, have been observed to search and take prey species through these reef areas during both slow and fast current speed periods. Scup were observed to feed in a scan and pick mode on adjacent sand plains around the reefs and rock surfaces. Atlantic silversides preyed only on planktonic prey species.

DISCUSSION

Observations at current-dominated rocky reef sites off southern New England revealed that changing current velocity is a factor limiting and shifting the spatial distribution of fishes by size class. For example, as current velocity decreased, a species or size class group with an overlapping prey preference with a different species or size class group was able to extend its range into prey refuge areas which were previously inaccessible due to high current velocity.

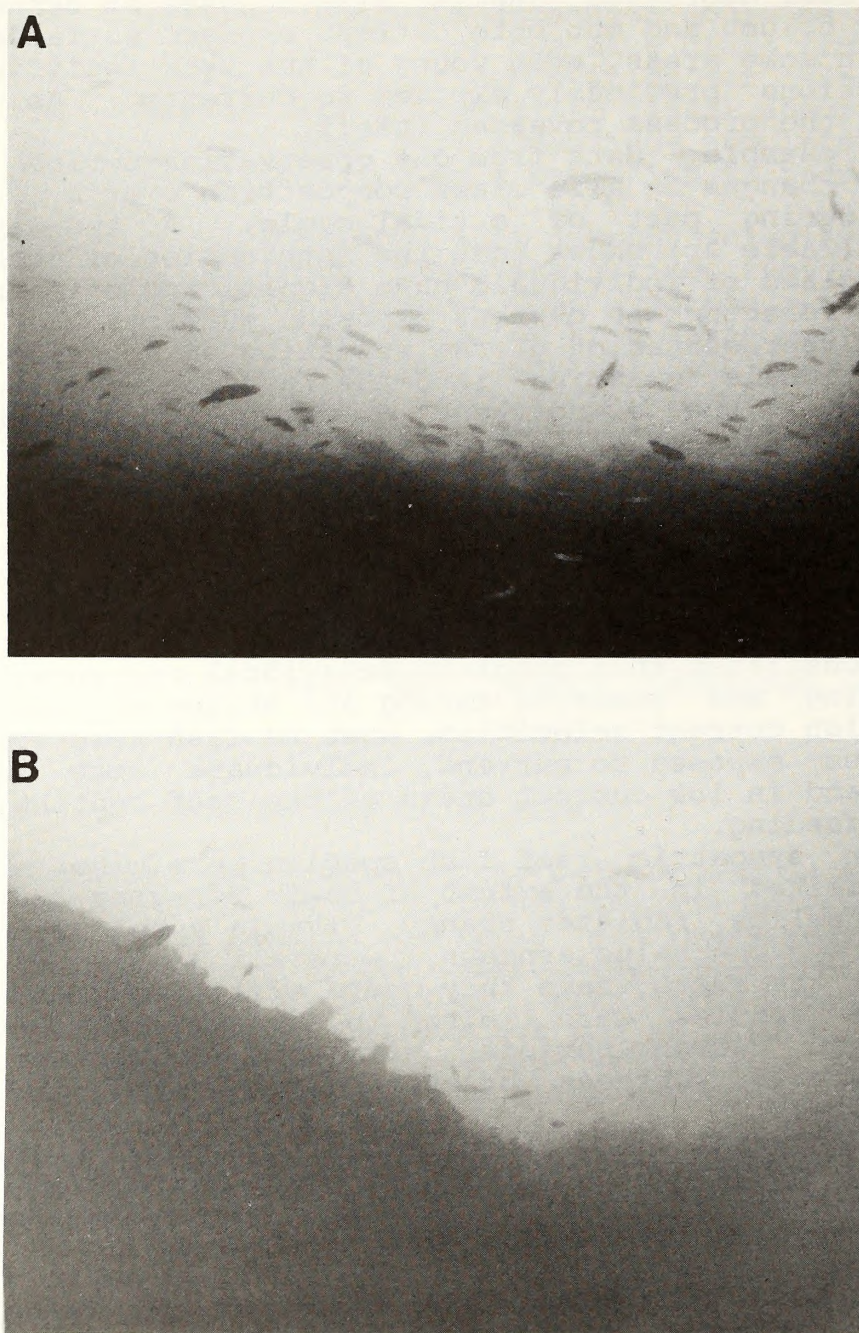


Figure 1. A) An aggregation of cunner at slack current. All size classes present on the reef are swimming above the reef infrastructure. B) After the tide has turned (current velocity less than 0.25 kt) many individuals and the smallest size classes have moved closer to the substrate. C,D, and E on opposite page: C) At higher current velocities (in this photograph, approximately 0.75 kt) only the largest size class individuals are able to maneuver in the current. Note the single large cunner (approximately 140 mm TL) and how the macroalgae are bent over in the direction of flow. D) A small cunner (approximately 50 mm TL) sheltered in a crevice from the current. E) Cunner exhibiting the common scan and pick feeding mode. Note the individual in the center biting at Tubularia sp.

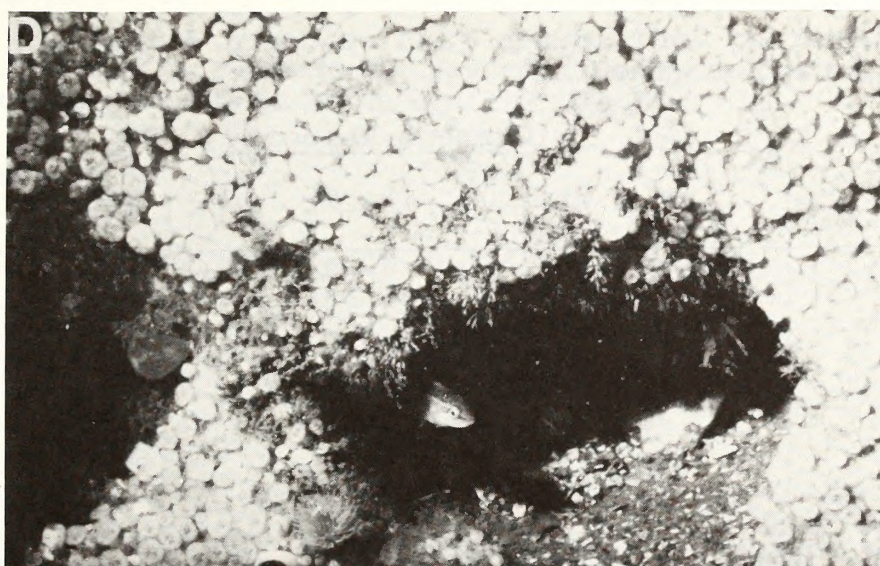
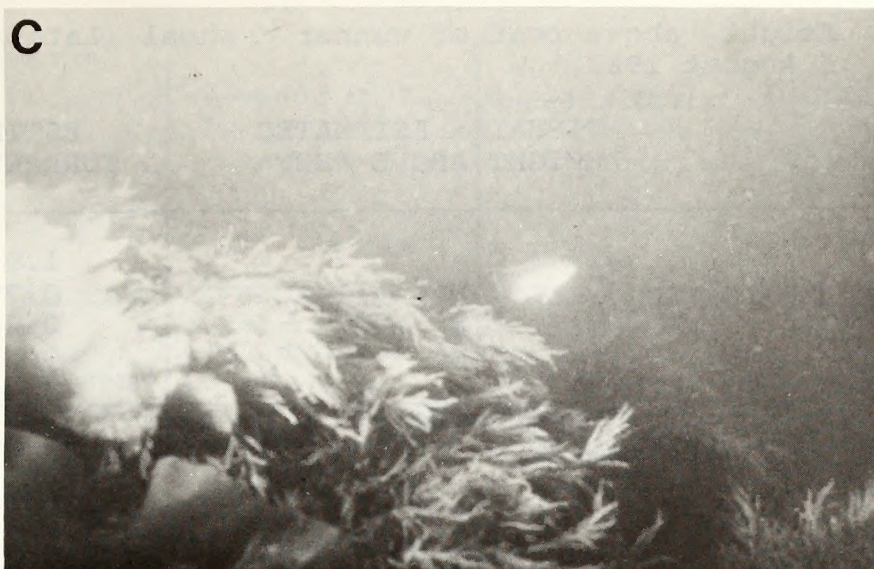


Table 1. Height above reef of cunner 1. shoal (Latimer Reef 2. -
6 August 1983):

TIME	VISUALLY ESTIMATED HEIGHT ABOVE REEF	ESTIMATED CURRENT SPEED
1245	0	1.5 kt.
1300	< 1 m	0.75 kt.
1315	1 m	0.25 kt.
1330	> 3 m	0

1. - Observations of largest size class present.

2. - Depth approximately 10 m.

Table 2. Size class composition of cunner observed over current
exposed surface at different tidal current speeds (fn. 1).

(a) Mean number of individuals (and standard deviation) over current
exposed surface (fns. 2,3):

Size Class	<u>Current Velocity</u>		
	1 kt.	1/2 kt.	0 kt.
Large	0.33 (0.58)	3.33 (1.53)	7.33 (2.08)
Medium	0.33 (0.58)	3.67 (1.53)	10.33 (2.08)
Small	0.00 (0.00)	0.00 (0.00)	9.00 (2.65)

b) Two-way analysis of variance:

<u>Source</u>	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	
Size class	2	14.52	7.26	3.16	significant at p .10
Current Speed	2	367.63	183.81	78.89	significant at p .005
Interaction	4	23.93	5.98	2.57	significant at p .10
Error	18	42.00	2.33		
Total	26	448.07			

1. - Observations at Beebe Cove, Groton, Connecticut, on 10
December, 1983. Tidal stage observed was high slack to ebb.

2. - Data from three 1-minute observation periods per size class
at each current speed stage.

3. - Size class groupings for individuals was by visual
approximation (i.e., large 60 mm TL; Medium 40-60 mm TL;
small 40 mm TL).

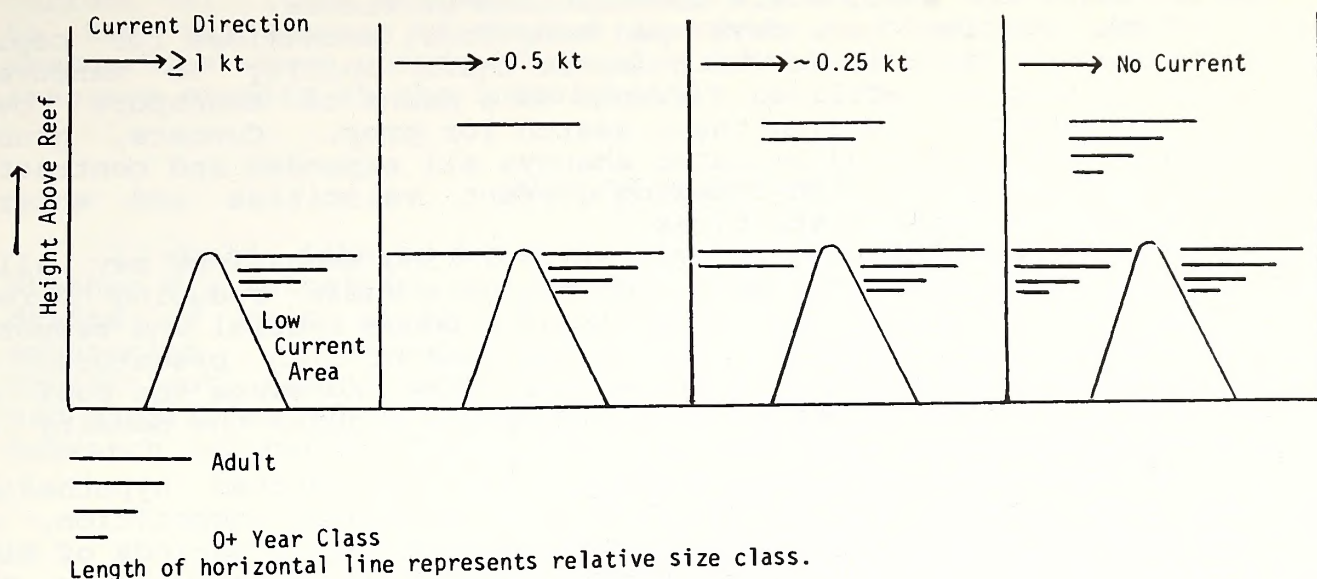


Figure 2. Schematic representation of the distribution of cunner in relation to current speed on a typical reef.

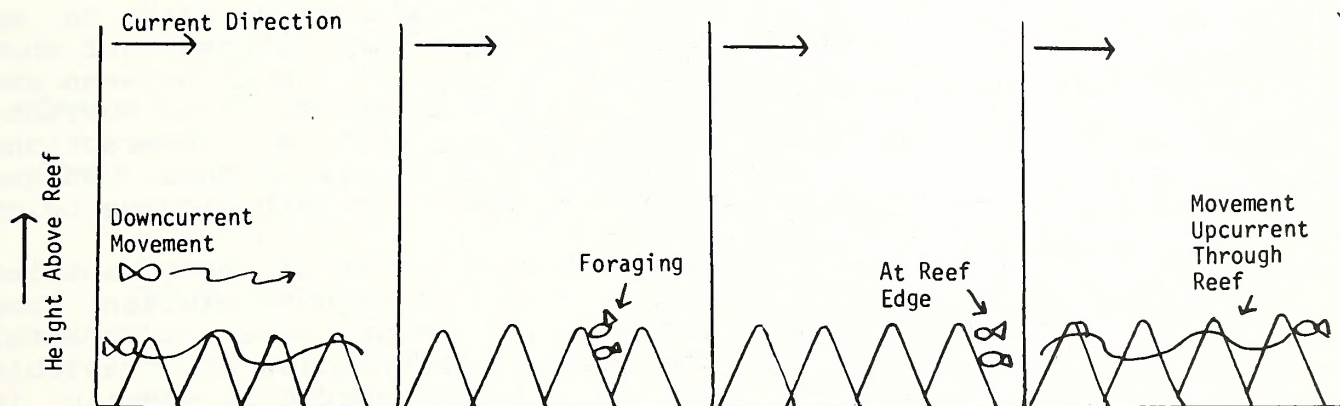


Figure 3. The general chronology of movement over a reef of cunner utilizing currents as a transport mechanism in the downcurrent direction.

By moving, the pool of potential prey and search area increases, while the density of potential competitors is reduced.

Blaxter (1969) reviewed data regarding endurance speeds and burst speeds of some commercially important species and showed significant differences between species and between size classes within species. Studies by Howard (1980) and Howard and Nunny (1983) showed that the distribution of lobster, *Homarus gammarus*, is limited by tidal current and wave action to low current areas of the seabed, also on a size selective basis. Differences in current speed regimes at several coral reef sites have been found to effect the distribution, abundance and diversity of diurnal and nocturnal planktivorous fishes (Hobson and Chess, 1978; Thresher, 1983). These studies are consistent with the observation that current velocity

can restrict the small scale distribution of fishes.

Fish species have developed behavioral mechanisms for coping with current velocities which impair their ability to maneuver. Cunner sometimes utilized currents as a means of transport over reef surfaces, extending their search for prey. Cunnners, grubby sculpins, rock eels and radiated shannys all expanded and contracted their distribution with changing current velocities and entered shelter at the appropriate times.

These physical and behavioral isolating mechanisms may allow predators to utilize the same prey resource while reducing direct competition. Current dominated areas produce spatial and temporal prey refuges from specific size classes of fish predators. An individual's maneuverability in such an area increases the pool of potential prey and at specific tidal stages reduces the density of potential direct competitors.

If one were to make predictions from the stated hypothesis, then some amount of consumptive and encounter competition, as described by Schoener (1983), probably occurs during periods of high current speeds when there is maximum packing of individuals in the reef infrastructure. Since cunner are the dominant species, have limited home ranges (Green, 1975; Olla *et al.*, 1975) and have a biomass exceeding values for some tropical reef fish communities (Sand, 1982), these interactions may be maximized (but not necessarily extreme) at this point. Food habits data on an assemblage from a simultaneous sample at this tidal stage might show a maximum amount of partitioning of prey resources, both between and within species. Conversely, at periods of lessening tidal current, dispersion of individuals occurs and competitive interactions should be reduced. Food habits data from a sample at these stages should show a decreasing amount of prey resource partitioning owing to the expanded potential prey pool.

It is difficult to assess the actual amount of prey species overlap which occurs on a small scale since no high resolution food habits studies have been conducted for northwest Atlantic coastal reef fish communities. The previously cited studies of trawlable demersal assemblages do indicate a significant amount of overlap in specific species groups and within species on a large scale. Bigelow and Schroeder (1953) show many common prey taxa for the principle species discussed which suggests some amount of overlap would occur. Simultaneous sampling of sympatric species which is sensitive to spatial and temporal variations is essential in determining how prey resources are utilized (Chess, 1979).

The role of disturbance mechanisms in mediating coexistence in a variety of assemblages has been well documented in the ecological literature (Dayton, 1971; Weins, 1977; Caswell, 1978; and many others). I suggest that cyclic changes in tidal current velocity may affect fish assemblages in a manner similar to the effects of predation and physical disturbance on other faunal assemblages.

In the northwest Atlantic, an area with semidiurnal tides, tidal heights vary from 3 to 4 m in the Gulf of Maine and 1 to 1.5 m off the southern New England coast. Current velocities vary by area depending upon the bottom topography. Many areas commonly have maximum tidal velocities in excess of 1 knot. Therefore, fish assemblages in this region are subject to varying degrees of current-induced changes in small scale distribution. Changing

current velocities may be an important mediating factor contributing to the maintenance of species diversity in temperate marine fish communities where component species exhibit various degrees of prey resource overlap at the intraspecific and interspecific level.

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PRE AND POST DRILLING BENCHMARKS AND MONITORING DATA OF OCEAN
FLOOR FAUNA, HABITATS, AND CONTAMINANT LOADS ON GEORGES BANK AND
ITS SUBMARINE CANYONS

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ABSTRACT

Diver scientists from several New England research institutions (NMFS, NURP, USGS) conducted a before, during and post-drilling study of the species abundance, community structure, animal-substrate relationships and body-substrate burdens of trace metals, PCB's and hydrocarbons within and downstream of oil and gas exploration areas on the south central portion of Georges Bank. There was no evidence of impact from drilling on the megabenthic fauna and the quality of their ocean floor habitats on Georges Bank and within the Georges Bank Submarine Canyons. The five (5) year (1980-1984) "benchmark" and monitoring study, conducted from the research submersible Johnson-Sea-Link, was supported by NOAA's Office of Undersea Research (OUR) and the National Marine Fisheries Service, Woods Hole, MA.

INTRODUCTION

From 1971 through 1986 the Manned Undersea Research and Technology (MURT) Program, NMFS, Woods Hole, MA, and the National Undersea Research Program, University of Connecticut, Avery Point (NURP-UCAP) conducted in situ studies of the megabenthic (large, bottom dwelling) fauna and flora of the inner and outer continental shelf, and upper slope from Cape Hatteras to eastern Georges Bank and the Northeast Channel (Figure 1). These studies partially focused on (1) species abundance, habitat preference and behavior of the megabenthic fauna of Georges Bank and the Georges Bank Submarine Canyons, (2) community structure and (3) variations in these community and species parameters/characteristics over a 5 year period (1980-1984). Various publications (Cooper and Uzmann, 1971; Uzmann et al., 1978; Valentine et al., 1980a, b; Cooper and Uzmann, 1980a, b, 1981; Meyer et al., 1981; Able et al., 1982; Cooper et al., 1982; Valentine et al., 1984a, b; Shepard et al., 1986; Cooper et al., 1987) have reported the results of these studies. Included in this research activity were studies directed towards calibrating and assessing the effectiveness of conventional research survey and commercial catch gear (lobster trap, gill nets, "ghost" nets and traps, otter trawl, clam dredge, camera sled, etc.) and documenting their impact on the ocean floor and its fauna.

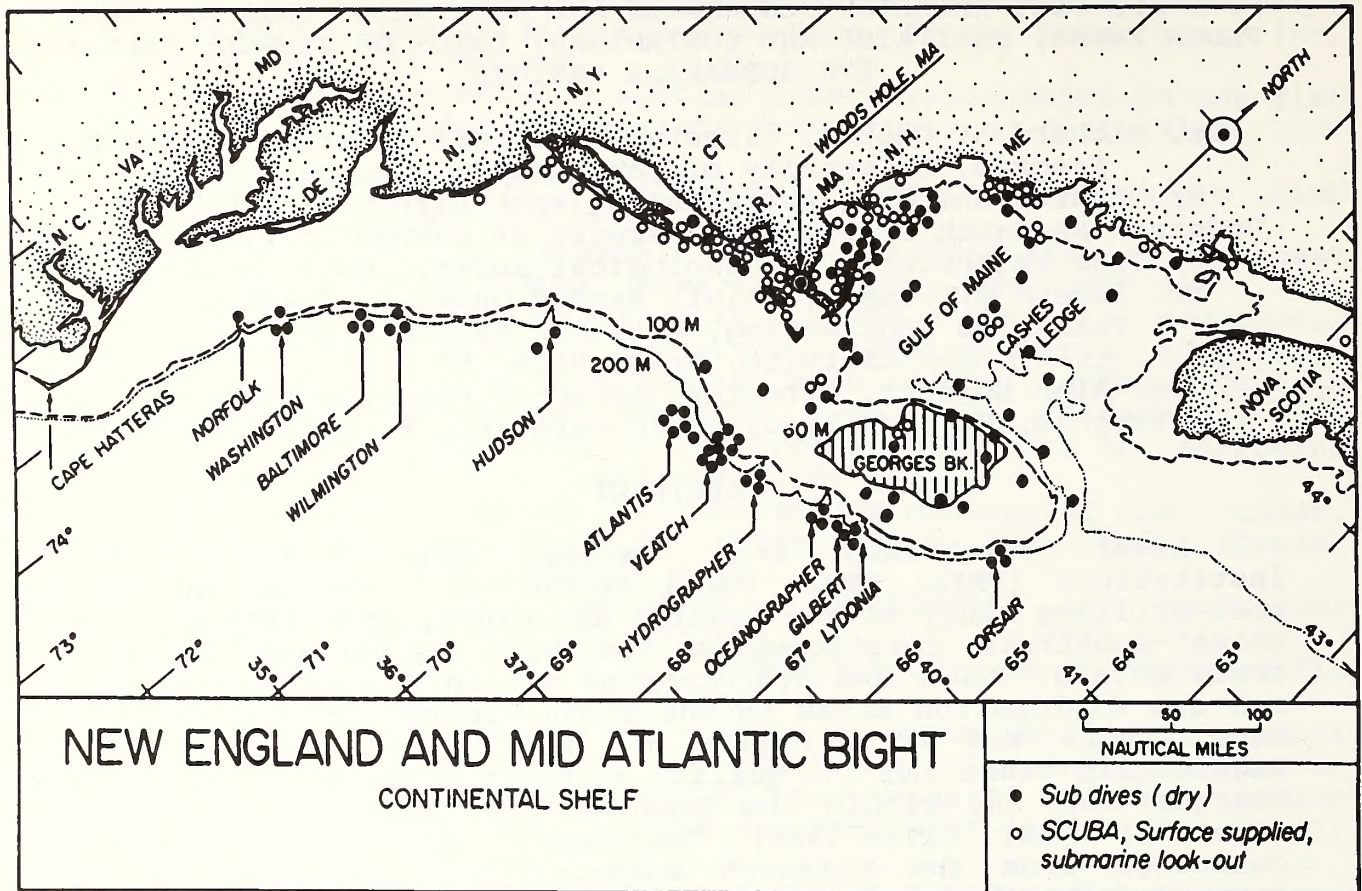


Figure 1 - Undersea research sites of Manned Undersea Research and Technology Program and the National Undersea Research Program, University of Connecticut, for the period 1971 through 1986.

Most of the submersible work took place within the Gulf of Maine, on Georges Bank and in or around the Georges Bank and Middle Atlantic Bight submarine canyons (Corsair, Lydonia, Gilbert, Oceanographer, Hydrographer, Veatch, Atlantis, Block, Hudson, Baltimore, Washington and Norfolk; Figure 2). Approximately 600 manned submersible dives have been made in support of this combined research effort, utilizing 10 different dive systems. Several unmanned ROV's (Snoopy, Recon IV, Mini-Rover Mark I and II, Phantom 300 and Super Phantom) have recently been applied to this undersea research program.

In response to scheduled (July 1981-September 1982) exploratory drilling (eight holes) for oil and natural gas on south-central Georges Bank (Lease Sale Area 42, Figure 2), and expected exploratory drilling along the continental slope south and west of Georges Bank (Lease Sale Area 52, Figure 2), we began a pre-drilling (benchmark) definition and monitoring investigation to identify impact, or lack of impact, on the living resources of the ocean floor and their habitats.

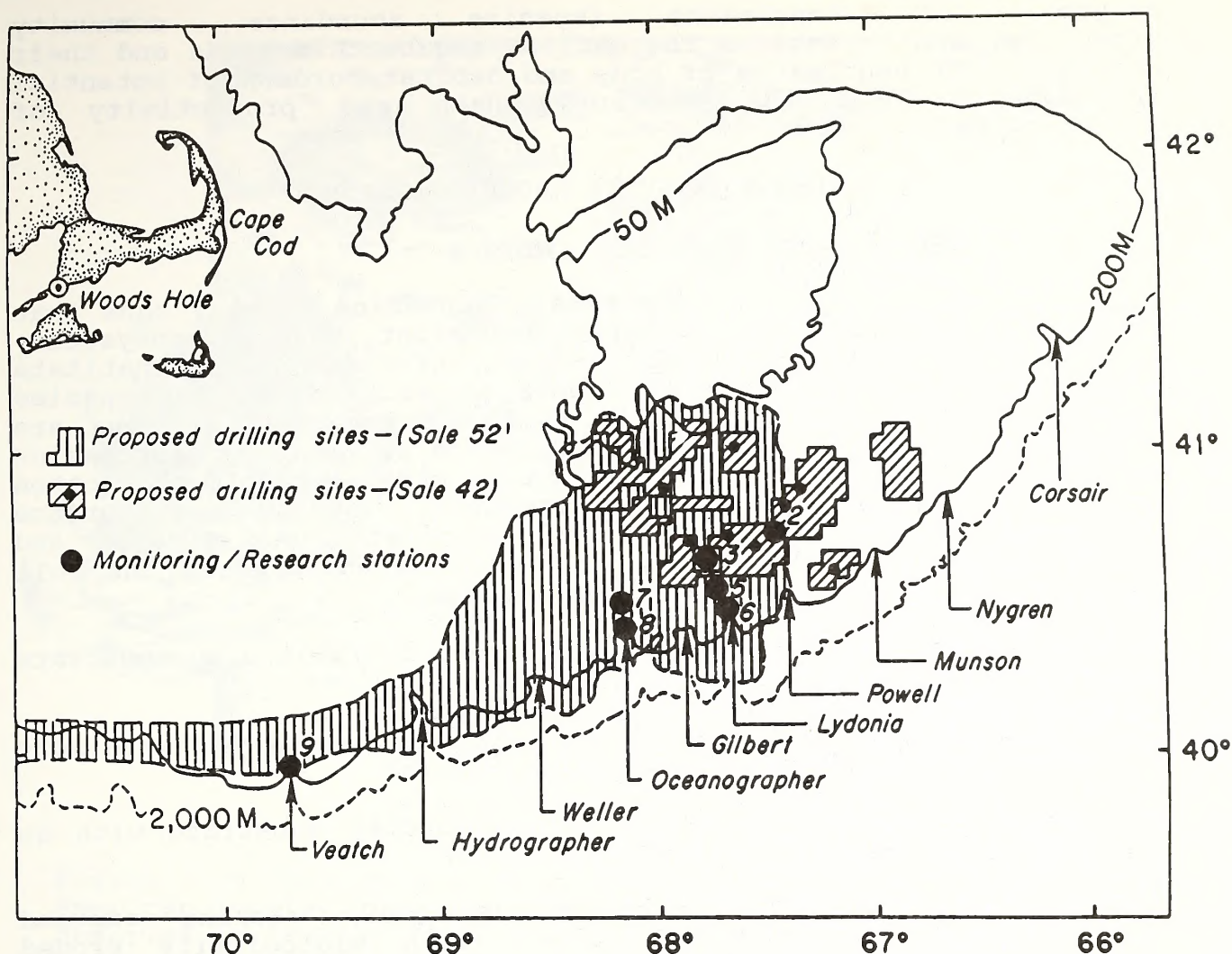


Figure 2 - Location of site specific "benchmark" and monitoring stations revisited annually by the Johnson-Sea-Link II submersible, 1980 through 1984. Sites of eight exploratory holes drilled by oil companies from July, 1981 through September, 1982 are identified. Stations 5 and 6, 7 and 8, and 9 were located in the heads of Lydonia, Oceanographer, and Veatch Canyons, respectively.

Scientists from the U.S. Geological Survey, Woods Hole, MA., participated in this study. Twelve years of experience in conducting in situ research and deep diving operations on the continental shelf and slope was utilized in defining the sampling design and operational procedures.

We began the benchmark and monitoring study in the summer of 1980 as part of NOAA's Northeast Monitoring Program (NEMP). The following sections of this article briefly summarize the results of this five year study with emphasis placed on (1) the biology and ocean floor habitat types of Georges Bank and its submarine

canyons, (2) benchmarks (species abundance, community structure, and variations thereof) of megabenthic fauna and their habitats, (3) benchmarks of body and habitat burdens of potential contaminants, and (4) the uniqueness and productivity of submarine canyon heads.

METHODS, RESULTS AND DISCUSSION

Biology and Habitats of Submarine Canyons

Our studies of the Georges Bank submarine canyons show that these large geological features represent unique ecosystems, largely because of their highly varied, three dimensional habitats (Valentine et al., 1980a, b; Cooper et al., 1987). The species abundance and community structure of the megabenthic fauna are closely related to the surface geology and sedimentary features of the canyon walls and axes, which in turn are related to the bottom gradient and currents. The sedimentary features and surface geology produce the following five habitat types (Cooper and Uzmann, 1980b; Cooper et al., 1987), which encompasses the full range of ocean-floor environments observed.

- I Flat, featureless or mildly featured, mud/silt/clay substrate with less than 5% overlay of gravel;
- II Level or gradually sloping mud/silt/clay substrate with more than a 5% overlay of gravel/rock/cobble;
- III Level to steeply sloping (50°) sand/clay substrate with an overlying boulder field;
- IV Gradually (3°) to precipitously (70°) sloping exposed silt/clay substrate (compacted) with biologically eroded excavations of various shapes and sizes, which we call a "Pueblo Village" (Figure 3); and
- V Featured sand dunes/waves with overlying sand ripples.

We hypothesize that submarine canyons function as refugia for many bottom-oriented species, where there is little, if any, impact from active fishing gear (Valentine et al., 1980b). Both species diversity and abundance are greater in canyons than in noncanyon areas at comparable depths (Cooper et al., 1987). Canyons also function as important nursery grounds for a wide variety of bottom-oriented species such as shrimps, Cancer spp. crabs, American lobster, white hake, cusk, ocean pout, conger eel, tilefish, blackbellied rosefish, etc., and provide three-dimensional shelter, rarely occurring in noncanyon areas of the outer shelf and slope, for the adults of some 20 species. The highly significant animal-habitat associations observed within the canyons were considered in designing our site-specific benchmark and monitoring studies (Cooper and Uzmann, 1980b), as discussed below.



Figure 3 - Galatheid crabs, Cancer spp. crabs, cleaner shrimp, American lobster, blackbellied rosefish, and tilefish, as actually observed in "Pueblo Village" habitat at 200 m in Veatch Canyon.

Benchmarks of Megabenthic Fauna

MURT began defining quantitative and qualitative benchmarks (pre-drilling) of species abundance, community structure, and animal-substrate relationships in July 1980, at two stations on Georges Bank and two stations in Lydonia Canyon (Figure 2) thought to be potential reservoirs for bottom-carried sediments and entrained contaminants. Revisitation to these monitoring sites and estimation of selected species and community parameters, in 1981 through 1984, provided estimates of parameter variability from year to year as well as an assessment of impact from exploratory drilling. Exploratory drilling occurred at eight locations (Figure 2) on Georges Bank from August 1981 through September 1982. In July 1981, we established two additional stations in Oceanographer Canyon and a seventh station in Veatch Canyon in July 1982. Thus, we have five consecutive years of data from Georges Bank and Lydonia Canyon, four years of data from Oceanographer Canyon and three years of data from Veatch Canyon. For logistical and financial reasons, the month of July represented the time of the year when each of these study sites was initially examined and subsequently revisited.

Each study site was marked with a 37 khz pinger (5 year battery) embedded in a pyramid-shaped cement block. We collected our benchmark and monitoring data primarily through the use of the Johnson-Sea-Link I and II submersibles. Dive systems were chartered from the Harbor Branch Oceanographic Institution with support from NOAA's Office of Undersea Research (OUR), Rockville, Maryland, which has supported virtually all of our undersea research since 1971. Four photographic transects (north, south, east and west) were conducted at each station with the submersible cruising 600 yards along the bottom at a fixed altitude (one to two feet) over the bottom, radiating out from or in toward the station marker. Using two externally mounted (forward and aft), bulk-loaded cameras with 100 watt-second strobes, we took between 1500 and 2600 color photographs (35 mm, high speed Ektachrome film), representing between 10,000 and 18,000 m² of ocean floor, at each study site. Frequency of camera "firing" was 8 to 12 seconds throughout the entire length of each transect.

At our laboratory, each 100 foot role of film was projected and magnified (15 x) on a film reader. Judgements were made as to the accuracy, resolution and proper imaging of each photographic frame prior to analyzing the frame for species abundance and community structure data. Improper altitude control of the submersible over the bottom negated the calibration of the photographic technique and resulted in the rejection of between 5 and 30% of the photographs taken at a given station. Each "properly" taken photograph encompassed 7 m² of the ocean floor. Maintaining proper photographic procedures over a topographically rugged bottom was relatively difficult to effect. Occasional camera malfunctions resulted in additional losses of photographic documentation. Other benchmark and monitoring data were collected by (1) making direct observations and recording them on audio tapes, (2) video recordings on 3/4 inch color tapes and (3) sampling surface sediments and selected biota (e.g. anemones, sea scallops and lobsters) in situ using the robotic arm of the submersible. In addition, trapping, sediment grabs and "hook and line" techniques were effectively used from the surface vessel (mother ship to the submersible) to augment the in situ collections.

We have generated a large inventory of species abundance, community structure, animal-substrate association and animal-depth distribution data, all categorized and analyzed as a function of habitat type and station over a 3 to 5 year period. We have also collected a considerable data base, through in situ observations and video documentation, on the behavior and general ecology of the megabenthic fauna of Georges Bank and its associated submarine canyons (Cooper and Uzmann, 1980a; Valentine et al., 1980a, b; Cooper et al., 1987). This report will present a brief summary of the results of this benchmark and monitoring program. A more detailed report is currently being prepared with the species abundance data being subjected to appropriate transformations, and further statistical analysis.

Following is a list of the megabenthic species most commonly observed/photographed at the Georges Bank, Lydonia Canyon, Oceanographer Canyon, and Veatch Canyon study sites from 1980 through 1984.

<u>Common Name</u>	<u>Scientific Name</u>
Mud anemone	<u>Cerianthus borealis</u>
Rock anemone	<u>Bolocera</u> sp.
	<u>Tealia</u> sp.
Sea pens	<u>Pennatula aculeata</u>
Starfish	<u>Astropecten</u> sp.
	<u>Asterias vulgaris</u>
Cancer (Jonah) crab	<u>Cancer borealis</u>
	<u>Cancer irroratus</u>
Portunid crab	<u>Bathynectes superba</u>
Hermit crab	<u>Pagurus</u> sp.
	<u>Catapagurus</u> sp.
Galatheid crab	<u>Munida</u> sp.
Lobster	<u>Homarus americanus</u>
Sea scallop	<u>Placopecten magellanicus</u>
Squirrel hake	<u>Urophycis chuss</u>
White hake	<u>Urophycis tenuis</u>
Silver hake	<u>Merluccius bilinearis</u>
Cod	<u>Gadus morhua</u>
Ocean pout	<u>Macrozoarces americanus</u>
Sculpin	<u>Myoxocephalus</u> sp.
4-spot flounder	<u>Paralichthys dentatus</u>
Skate	<u>Raja</u> sp.
Conger eel	<u>Conger oceanicus</u>
Goosefish	<u>Lophius americanus</u>
Blackbellied rosefish	<u>Helicolenus dactylopterus</u>
Tilefish	<u>Lophalatilus</u>
	<u>chamaeleonticeps</u>
Cunner	<u>Tautogolabrus adspersus</u>
Spiny dogfish shark	<u>Squalus acanthias</u>

Hereafter these species will be referred to by their common names. Sometimes we could not distinguish between species of the same genus from the photographs, thus the counts of more than one species of mud anemones, starfish, cancer crabs and hermit crabs were combined. It should also be noted that two species demonstrated either a strong positive attraction (spiny dogfish shark) or avoidance reaction (cod) to the submersible, thus, these species were omitted from the analysis. All other megabenthic fauna demonstrated little, if any, reaction to the submersible, thus, their abundance estimates are considered valid.

Annual abundance estimates for selected megabenthic species, by habitat type, are presented in Appendix Tables 1 through 13 for stations 2 and 3 (Georges Bank), 5 and 6 (Lydonia Canyon), 7 and 8 (Oceanographer Canyon), and 9 (Veatch Canyon). Stations 2 through 7, however, are considered to be the most important locations with regard to potential impacts from drilling operations and establishing a multi-year benchmark for future commercial operations on Georges Bank.

Distribution of annual abundance estimates (numbers per 10,000 m², Hectare) are presented in Figure 4 (stations 2 and 3 - Habitat type I), Figure 5 (station 5 -Habitat types I and II

combined; station 6 - Habitat type I) and Figure 6 (station 6 - Habitat types II and III). Distributions of abundance estimates for stations with four years of data or less are not presented. Ninety percent confidence limits are plotted about the grand mean abundance values for those species that do not clearly demonstrate an upward or downward trend in abundance over the time period in question. For those species that appear to be undergoing a trend in abundance, a least squares line of best fit has been fitted to the data (e.g. galatheid crab, station 5; starfish, mud anemone, and jonah crabs, station 6) in Figures 5 and 6.

Of the 30 or more megabenthic species that inhabit Georges Bank and its canyons to depths of 350 m, 14 are likely candidates for long-term monitoring as "key indicator" species reflecting possible impact from drilling activity. The criteria (Cooper and Uzmann, 1981) for key indicator species designation are: (1) endemic to study area during summer, (2) specific habitat-type association, (3) relatively long (4-5 years or more) life span, (4) relatively high population level, (5) population level not subject to large fluctuations through year-class input, and (6) individuals easily counted from photographs. Any species that meets or approximates five of these criteria have been designated as key indicator species, such as the mud anemone, rock anemone, starfish, sea pen, sea scallop, cancer crab, galatheid crab, ocean pout, conger eel, white hake, squirrel hake, blackbellied rosefish, tilefish and 4-spot flounder.

Examination of Appendix Tables 1-13 and Figures 4-6 suggests the following with regard to the identification of "key indicator species" by habitat type, and in some cases specific monitoring sites:

1. Rock anemones, ocean pout, conger eels, white hake, blackbellied rosefish and tilefish probably represent the best key indicator species for a type III Habitat.
2. Sea scallops, starfish, cancer crabs, and squirrel hake represent good monitoring species for the Type I Habitats of Georges Bank, but not for the submarine canyons.
3. Starfish, cancer crabs, and 4-spot flounder represent good monitoring species for Habitat Types I and II for the submarine canyons.

Further examination of the benchmark data on annual variations in species abundance, specifically for the key indicator species, suggests that no one species is likely to reflect anything other than a major impact from production drilling. We therefore suggest that a "community composition" approach to defining faunal benchmarks and faunal monitoring be considered in terms of future oil and gas explorations and monitoring activities. Furthermore, we suggest that community composition be examined by Habitat type and location (Georges Bank, submarine canyon head and walls, etc.). For example, the megabenthic communities described in this study, defined on the

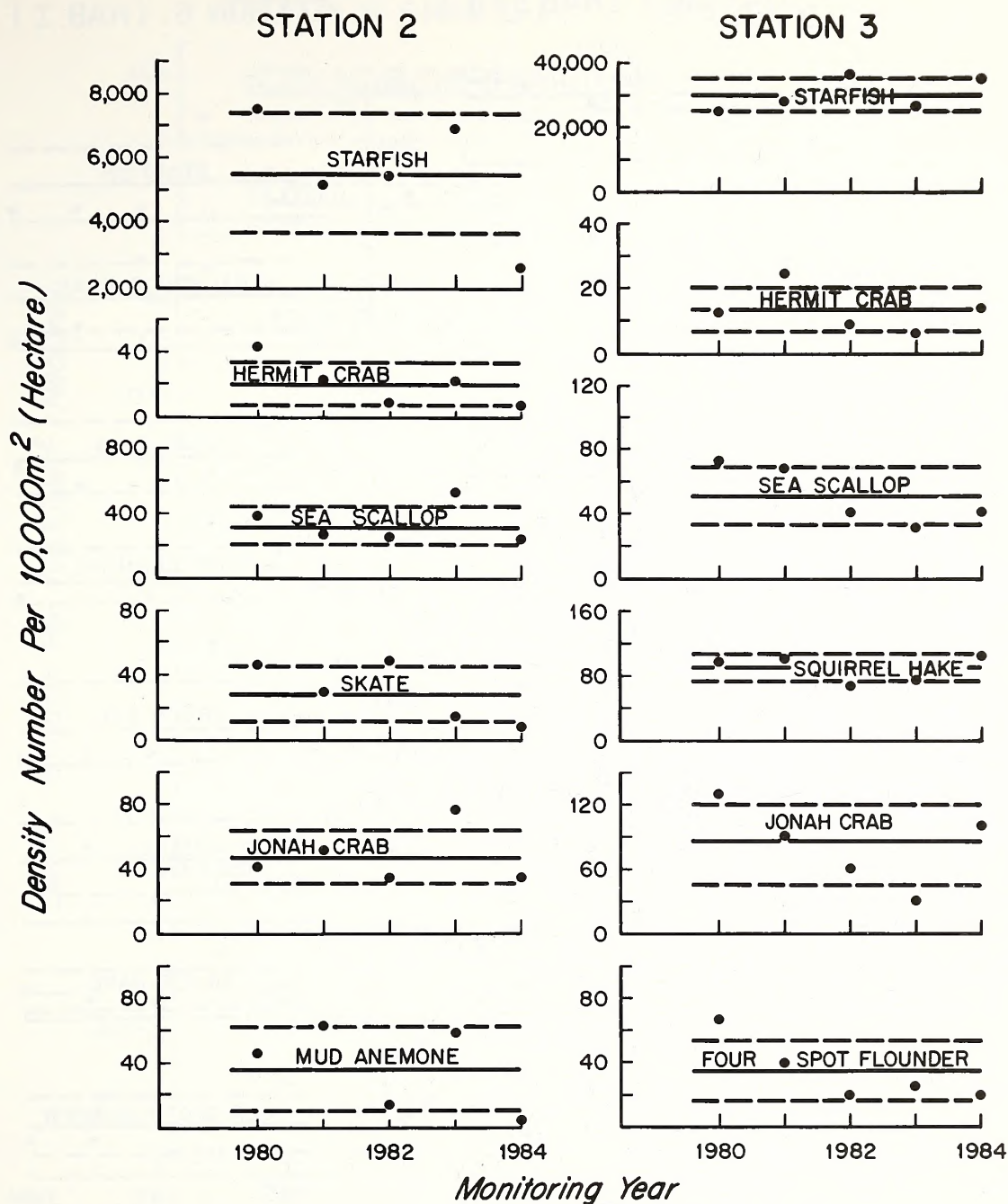


Figure 4 - Distribution of annual abundance estimates (numbers per 10,000 m², i.e. hectare) of selected megabenthic fauna at stations 2 and 3, habitat Type I, from July 1980 through July 1984. Significant trends in abundance were not identified for any species; grand mean abundance with 90% confidence limits are portrayed.

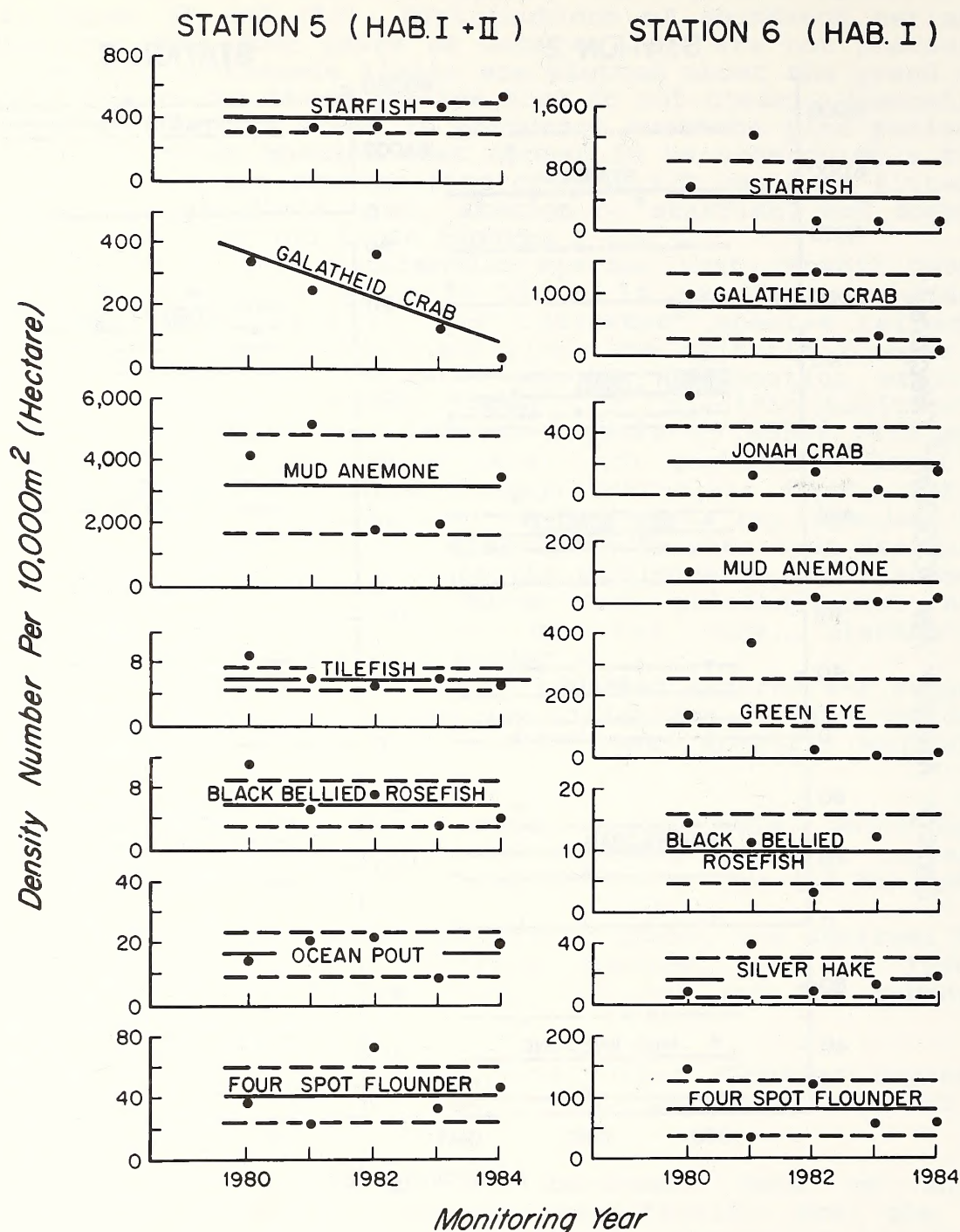


Figure 5 - Distribution of annual abundance estimates (numbers per 10,000 m², i.e. hectare) of selected megabenthic fauna at station 5, habitat Types I and II combined, and station 6, habitat Type I, from July 1980 through July 1984. Grand mean abundance, with 90% confidence limits, are portrayed for all species, with the exception of galatheid crabs (station 5) which demonstrated a significant downward trend in abundance.

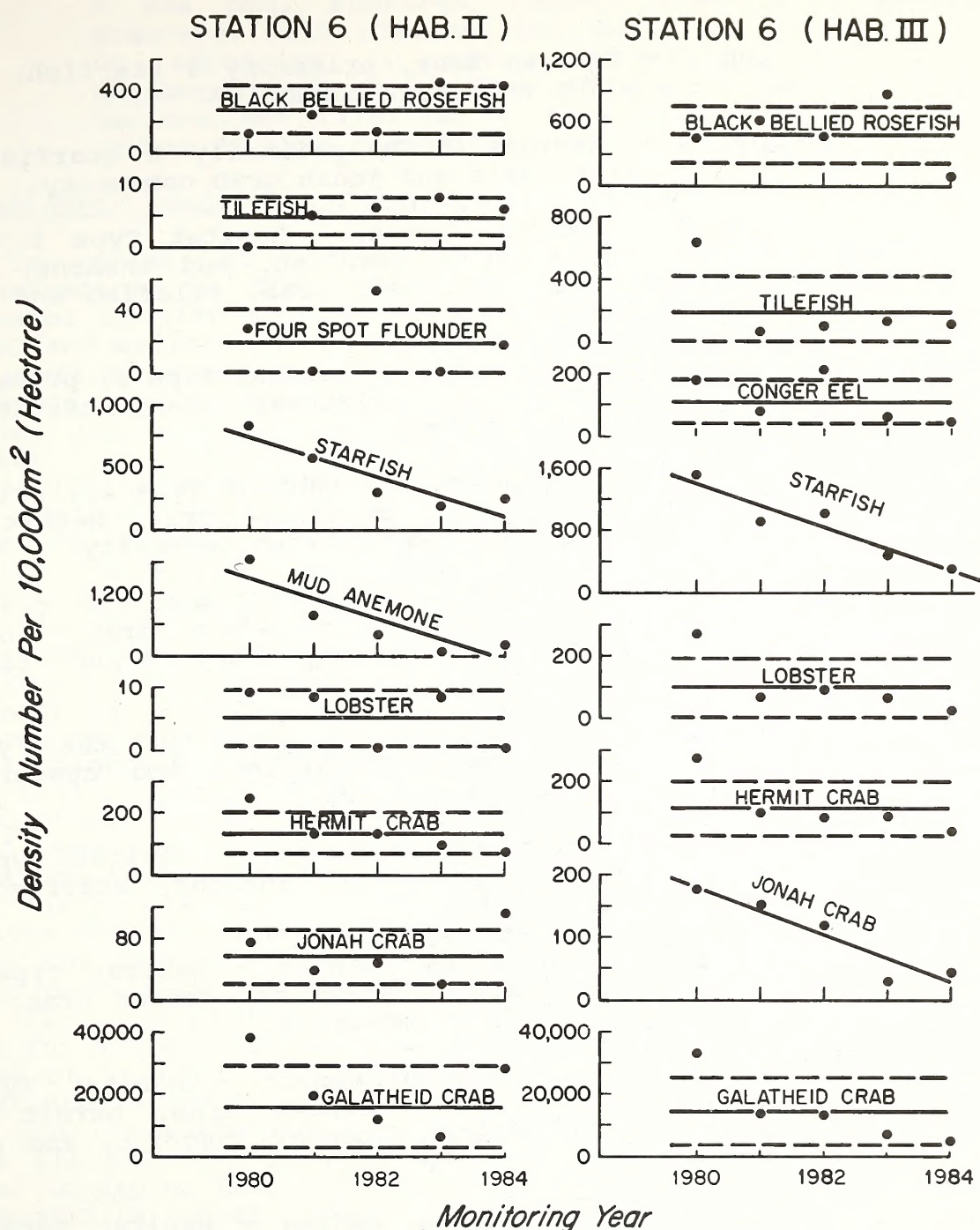


Figure 6 - Distribution of annual abundance estimates (numbers per 10,000 m², i.e. hectare) of selected megabenthic fauna at station 6, habitat Types II and III, from July 1980 through July 1984. Grand mean abundance, with 90% confidence limits, are portrayed from all species with the exception of starfish and mud anemones (habitat Type II), and starfish and Jonah crabs (habitat Type III), which all demonstrated significant downward trends in abundance.

basis of numerical dominance and biomass could be described as follows:

1. Station 2 - Georges Bank, primarily a starfish, cancer crab, sea scallop and skate community.
2. Station 3 - Georges Bank, primarily a starfish, sea scallop, squirrel hake and jonah crab community.
3. Station 5 - Lydonia Canyon - Habitat Type I and II (combined), primarily a starfish, mud anemone, cancer crab, hermit crab, galatheid crab, tilefish and 4-spot flounder community.
4. Station 6 - Lydonia Canyon - Habitat Type I, primarily a starfish, cancer crab, galatheid crab, hermit crab and, 4-spot flounder community.
5. Station 6 - Lydonia Canyon - Habitat Type II, primarily a starfish, cancer crab, galatheid crab, hermit crab, greeneye, and blackbellied rosefish community.
6. Station 6 - Lydonia Canyon - Habitat Type III, primarily a starfish, galatheid crab, hermit crab, lobster, blackbellied rosefish, conger eel, and tilefish community.
7. Station 7 - Oceanographer Canyon - Habitat Type I, primarily a mud anemone, starfish, and cancer crab community.
8. Station 7 - Oceanographer Canyon - Habitat Type II, primarily a mud anemone, rock anemone, starfish, and cancer crab community.
9. Station 7 - Oceanographer Canyon - Habitat Type III, primarily a rock anemone, starfish, cancer crab, white hake, ocean pout, cunner community.
10. Station 8 - Oceanographer Canyon - Habitat Type I, primarily a mud anemone, cancer crab, hermit crab, shrimp, goosefish, 4-spot flounder, hagfish, and silver hake community.
11. Station 8 - Oceanographer Canyon - Habitat Type III, primarily a mud anemone, rock anemone, cancer crab, portunid crab, hermit crab, starfish, blackbellied rosefish, silver hake, and white hake community.
12. Station 9 - Veatch Canyon - Habitat Type I, primarily a sea pen, starfish, cancer crab, hermit crab, galatheid crab, 4-spot flounder, and blackbellied rosefish community.

13. Station 9 - Veatch Canyon - Habitat Type III, primarily a sea pen, starfish, hermit crab, galatheid crab, greeneye, and blackbellied rosefish community. Based on extensive in situ observations made of the megabenthic fauna at this station during the 1970s we believe the tilefish is also a significant (biomass) member of this community.

Contaminant Loads in Fauna and Sediments

In order to detect hydrocarbon and/or trace metal contamination in the surface sediments and tissues of key indicator species downstream of the exploratory drilling sites, animal and sediment samples were collected by submersible and from the surface vessel in July 1980, 1981, 1982 and 1983. Surface sediments and several (4-20) specimens of selected megabenthic species (Cancer crab and scallop - Georges Bank; Cancer crab, lobster and tilefish -Lydonia Canyon) were collected: scallops and sediments were collected in situ with the submersible, crabs were captured in pots, lobsters were purchased from commercial fishermen fishing at the study sites, and the tilefish were readily taken with hook and line by the crew members of the support vessel, R/V Johnson and submersible Johnson-Sea-Link.

The surficial sediments (2 cm below the sediment-water interface) were collected for trace metal (Barium, Ba; Cadmium, Cd; Copper, Cu; Chromium, Cr; Mercury, Hg; Lead, Pb; Zinc, Zn), hydrocarbon (aromatic and aliphatic), and PCB (several components) analyses. Scallop (muscle and viscera), cancer crabs (hepatopancreas and claw muscle tissue), lobster (hepatopancreas, claw/tail, muscle tissue, and eggs), and tilefish (dorsal musculature tissue) were subjected to the same analyses. Trace metal and hydrocarbon analyses followed the protocols of the Cambridge Analytical Associates (Cambridge, MA).

The levels of PCB's from sediment, cancer crab, tilefish and lobster samples collected from stations 2, 3, 5 and 6 in 1980 were below the levels of detection (0.005 ppm). Additional samples in later years were not collected for PCB determinations.

The samples (sediment and fauna) collected in 1980 through 1983 for hydrocarbon analyses contained FI hydrocarbons considered to be of biogenic origin and ranged from N.D. (non detectable) to TR (trace) to 0.53 ppm (tail and claw meat of lobster - station 6). The concentrations of petrogenic hydrocarbons (FI and FII) were all N.D. for all sediment and animal samples for two years prior to exploratory drilling and for two years after drilling had commenced in August, 1981.

Concentrations of trace metals analyzed from sediment and animal samples for 1980 through 1983 are presented in Appendix Tables 14 (stations 2 and 3) and 15 (stations 5 and 6). Each trace metal concentration represents a composite sample. Based on these trace metal concentrations the following conclusions have been made:

1. Trace metal concentrations in the surficial sediments at stations 2, 3, 5 and 6 remained relatively constant prior to and after drilling commenced. Of particular note are the

Barium levels: Barium, in the form of Barite, comprises a significant percentage, by weight, of drill muds. These concentrations are similar for both the Georges Bank and Lydonia Canyon stations

2. Cancer crab tissue contained similar levels of trace metals over a four year period, prior to and after the commencing of drilling operations. Concentrations found in the Lydonia Canyon samples were similar to those from Georges Bank.
3. Lobster claw and tail tissues were similar in levels of trace metals over time. The levels of trace metals from tilefish tissues were also constant over time and similar between stations 5 and 6.

Similar results were obtained by the U.S. Geological Survey during a three-year study that began in July 1981 to establish the concentrations of trace metals in sediments prior to drilling on Georges Bank, and to monitor the changes in concentrations that could be attributed to petroleum-exploration activities (Bothner et al., 1983; Bothner et al., 1985). Of the 12 elements analyzed in bulk (undifferentiated) sediments collected in the vicinity of drilling rigs on Georges Bank, only barium was found to increase in concentration after drilling commenced in July, 1981. One of the U.S.G.S. study sites was adjacent to Block 312 (Mobil), approximately 2 km northwest of our station No. 3. Bothner et al. (1985) found, "the maximum barium concentration is within the range of predrilling concentrations measured in various sediment types from the regional stations of this program." They determined that about 25 percent of the barite discharged at Block 312 was present in the sediments within 6 km of the drilling rig, four weeks after drilling was completed at this location. The barite discharged during the exploratory phase of drilling was associated with the fine fraction of sediment and widely distributed around the bank. Bothner et al. (1985) also found evidence for Ba transport to Great South Channel, 115 km west of the drilling area and as far east as 35 km, upstream from the drilling sites. Relatively small increases in Ba, present in the fine fraction of the sediment only, were detected 8 and 39 km downstream (seaward), in the heads of Lydonia and Oceanographer Canyons. Our surficial sediment samples were not processed to separate the fine grained sediments, thus our trace metal detection procedures are probably less sensitive than those reported by Bothner et al. For one year after completion of the well at Block 312 the concentration of barite decreased rapidly, probably a result of resuspension (up to 25 m above the sea floor), and sediment transport of barite-rich material present at the sediment water interface.

Assessment of Faunal Habitats

Animal-substrate relationships are difficult, if not impossible, to quantify, therefore, subjective interpretations have been made concerning the three-dimensional characteristics of

animal shelters (bowl-shaped depressions, excavated tunnels, scour basins around boulders and mud anemones, boulder fields, silt/clay flats, etc.), based on direct observations and extensive video documentation. Video documentation has been a powerful tool for judging the nature of animal-substrate relationships over the 5-year period and as a qualitative benchmark for future considerations regarding commercial drilling operations. Using the techniques described above, there has been no apparent change in animal-substrate relationships at stations 2, 3, 5, 6, 7, 8 and 9 during the course of this study.

CONCLUSIONS

Exploratory drilling operations for gas and oil on the south-central portion of Georges Bank during 1981 and 1982 had no measurable impact on the abundance of the megabenthic fauna, their habitats or contaminant loads on Georges Bank and three (3) of the Georges Bank Submarine Canyons (Lydonia, Oceanographer and Veatch). Consequently, the 3-5 year data base, discussed in this report, will be considered a benchmark against future commercial drilling operations conducted on Georges Bank or its adjacent outer continental shelf and submarine canyon regions. Significantly, recently released information indicates that Canadian petroleum companies may begin drilling operations on eastern Georges Bank in the very near future, upstream from our benchmark study sites.

ACKNOWLEDGEMENTS

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Appendix Table 1 - Annual abundance estimates for selected megabenthic species at station 2, habitat type I, for the period July, 1980 through July, 1984. Number photographic frames analyzed = 856, 395, 1052, 643, and 420 for 1980 to 1984, respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)					Grand Mean (90% Conf. Limits).
	(95% Confidence Limits)					
	1980	1981	1982	1983	1984	
Mud Anemone	45 (25-70)	62 (31-92)	14 (5-22)	58 (35-81)	3 (0-10)	36 (11-61)
Starfish	7,515 (7265-7765)	5,139 (4843-5435)	5,425 (5015-5829)	6,941 (6679-7203)	2,565 (2366-2763)	5519 (3681-7357)
Cancer Crab	41 (31-51)	51 (25-77)	34 (21-47)	76 (51-101)	34 (13-55)	47 (30-64)
Hermit Crab	43 (23-63)	22 (5-39)	8 (2-15)	22 (8-36)	7 (0-16)	20 (6-34)
Sea Scallop	382 (360-404)	264 (202-326)	244 (212-277)	518 (452-584)	221 (168-274)	326 (208-444)
Squirrel Hake	0 ---	0 ---	144 (112-175)	0 ---	0 ---	0 ---
Silver Hake	1 (0-4)	4 (0-11)	23 (11-35)	0 ---	0 ---	6 (0-26)
Ocean Pout	8 (2-14)	62 (31-92)	1 (0-4)	9 (0-18)	3 (0-10)	17 (0-41)
4-Spot Flounder	18 (12-24)	4 (0-11)	30 (18-42)	0 ---	0 ---	10 (0-33)
Skate	45 (33-57)	29 (9-49)	48 (45-50)	13 (2-24)	7 (0-16)	28 (11-46)

Appendix Table 2 - Annual abundance estimates for selected megabenthic species at station 3, habitat type I, for the period July, 1980 through July, 1984. Number photographic frames analyzed = 890, 1572, 1398, 225 and 460 for 1980 to 1984, respectively.

Species	Density - Number Per 10,000 m ² (Hectare)					Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)					
	1980	1981	1982	1983	1984	
Mud Anemone	0 ---	0 ---	8 (2-14)	6 (0-18)	0 ---	0 ---
Starfish	25,012 (24,577- 25,477)	27,840 (27,441- 28,238)	35,641 (35,022- 36,259)	25,911 (24,626- 27,196)	26,190 (25,152- 27,228)	28119 (23997- 32241)
Cancer Crab	133 (108-158)	91 (73-109)	59 (44-75)	32 (4-60)	62 (34-90)	75 (39-111)
Hermit Crab	13 (6-20)	25 (15-34)	9 (3-15)	6 (0-18)	9 (2-19)	12 (5-19)
Sea Scallop	73 (59-87)	69 (54-85)	41 (28-54)	32 (4-60)	62 (38-86)	55 (38-72)
Squirrel Hake	96 (74-118)	101 (76-126)	67 (50-85)	76 (27-125)	190 (136-244)	106 (59-153)
Silver Hake	24 (14-34)	10 (1-18)	38 (25-51)	6 (0-18)	15 (4-25)	19 (7-31)
Ocean Pout	54 (34-74)	22 (13-31)	7 (2-12)	32 (4-60)	87 (52-123)	40 (10-70)
4-Spot Flounder	66 (38-94)	40 (28-52)	20 (8-31)	25 (0-50)	16 (2-29)	33 (14-52)
Skate	28 (20-36)	17 (10-25)	11 (5-18)	76 (34-118)	84 (55-114)	43 (11-75)

Appendix Table 3 - Annual abundance estimates for selected megabenthic species at station 5, habitat types I and II combined, for the period July 1980 through July, 1984. Number photographic frames analyzed = 660, 1651, 1511, 975, and 1525 for 1980 to 1984, respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)					Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)					
	1980	1981	1982	1983	1984	
Mud Anemone	4159 (2972-5346)	5168 (3700-6636)	1760 (1394-2125)	1911 (1480-2342)	3533 (3077-3987)	3250 (1644-4855)
Starfish	327 (251-404)	344 (293-394)	347 (295-399)	485 (428-542)	551 (496-606)	411 (315-507)
Cancer Crab	205 (145-264)	40 (24-56)	330 (268-392)	48 (31-65)	73 (53-92)	139 (19-259)
Hermit Crab	125 (72-178)	1437 (1111-1763)	1646 (1466-1826)	699 (574-824)	432 (372-492)	868 (247-1489)
Galatheid Crab	343 (175-512)	246 (186-305)	357 (274-440)	125 (84-166)	38 (21-55)	222 (90-354)
Ocean Pout	14 (0-28)	21 (10-32)	22 (9-34)	9 (2-16)	19 (10-27)	17 (12-22)
Blackbellied Rosefish	11 (0-24)	5 (0-11)	7 (0-13)	3 (0-7)	4 (0-8)	6 (3-9)
Tilefish	9 (0-18)	6 (3-9)	5 (0-10)	6 (1-11)	5 (2-8)	6 (5-8)
4-Spot Flounder	36 (13-60)	23 (11-35)	72 (48-96)	32 (19-45)	46 (32-61)	42 (24-60)

Appendix Table 4 - Annual abundance estimates for selected megabenthic species at station 6, habitat type I, for the period July 1980 through July, 1984. Number photographic frames analyzed = 247, 375, 425, 351, and 319 for 1980 to 1984, respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)					Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)					
	1980	1981	1982	1983	1984	
Mud Anemone	0 ---	243 (67-418)	13 (3-27)	4 (0-12)	10 (0-25)	68 (0-205)
Starfish	567 (437-696)	1245 (1005-1485)	138 (89-187)	126 (82-170)	161 (96-227)	447 (0-907)
Cancer Crab	621 (398-844)	114 (74-154)	135 (89-180)	20 (2-38)	157 (66-247)	209 (0-434)
Galatheid Crab	972 (850-1093)	1245 (777-1713)	1328 (1015-1640)	301 (187-415)	49 (21-119)	779 (232-1325)
Hermit Crab	6889 (5464-8314)	2654 (2178-3130)	4309 (3750-4868)	2308 (1960-2656)	269 (154-384)	3286 (929-5643)
4-Spot Flounder	142 (78-206)	31 (7-54)	118 (80-155)	57 (28-86)	58 (17-99)	81 (37-126)
Greeneye	128 (61-195)	370 (267-472)	17 (2-32)	0 ---	9 (0-25)	105 (0-254)
Blackbellied Rosefish	14 (0-32)	11 (0-25)	3 (0-10)	12 (0-26)	0 ---	10 (4-16)
Lobster	34 (0-77)	0 ---	0 ---	0 ---	0 ---	0 ---

Appendix Table 5 - Annual abundance estimates for selected megabenthic species at station 6, habitat type II, for the period July, 1980 through July, 1984. Number photographic frames analyzed = 186, 534, 254, 448, and 448 for 1980 to 1984, respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare). (95% Confidence Limits)					Grand Mean (90% Conf. Limits)
	1980	1981	1982	1983	1984	
Mud Anemone	1828 (1099-2557)	727 (320-1133)	343 (210-476)	17 (0-50)	156 (7-255)	614 (0-1308)
Starfish	815 (639-992)	548 (430-666)	276 (206-345)	185 (106-264)	223 (169-277)	409 (154-664)
Cancer Crab	72 (27-126)	35 (16-54)	45 (14-76)	17 (0-40)	108 (54-163)	55 (22-89)
Galatheid Crab	38029 (38841-41216)	19236 (17565-20908)	11755 (10672-12837)	5681 (5015-6347)	2765 (2437-3092)	15,493 (2071-28,915)
Hermit Crab	242 (116-368)	123 (71-175)	124 (50-197)	92 (34-150)	70 (36-104)	130 (67-194)
4-Spot Flounder	27 (0-57)	0 ---	51 (18-83)	0 ---	16 (2-30)	19 (0-39)
Greeneye	959 (596-1322)	560 (374-746)	394 (269-518)	134 (49-219)	3 (0-9)	410 (52-768)
Blackbellied Rosefish	117 (51-183)	238 (183-293)	135 (118-152)	445 (310-580)	421 (343-498)	271 (124-419)
Lobster	9 (0-24)	8 (0-17)	0 ---	8 (0-18)	0 ---	5 (0-10)

Appendix Table 6 - Annual abundance estimates for selected megabenthic species at station 6, habitat type III, for the period July, 1980 through July, 1984. Number photographic frames analyzed = 19, 95, 49, 53, and 101 for 1980 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare).					Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)					
	1980	1981	1982	1983	1984	
Mud Anemone	0 ---	0 ---	29 (0-88)	0 ---	0 ---	6 (0-18)
Starfish	1491 (458-2524)	872 (587-1157)	991 (539-1444)	458 (248-668)	311 (176-446)	825 (379-1270)
Galatheid Crab	32456 (16794-48118)	13027 (10382-15671)	12682 (11404-13960)	6550 (4836-8264)	4201 (3330-5072)	13783 (3181-24385)
Hermit Crab	263 (0-564)	97 (3-191)	79 (0-170)	81 (0-198)	28 (0-67)	110 (24-195)
4-Spot Flounder	0 ---	0 ---	0 ---	0 ---	0 ---	0 ---
Greeneye	0 ---	0 ---	0 ---	0 ---	0 ---	0 ---
Blackbellied Rosefish	439 (0-889)	601 (409-794)	466 (184-749)	863 (492-1235)	863 (646-1080)	646 (449-844)
Conger Eel	175 (0-428)	75 (9-141)	204 (59-349)	54 (0-128)	42 (0-90)	110 (39-181)
Tilefish	614 (3-1225)	45 (0-112)	79 (0-170)	108 (5-211)	99 (17-181)	189 (0-417)
Lobster	263 (0-564)	60 (2-119)	79 (0-170)	54 (2-106)	14 (0-42)	94 (1-187)

Appendix Table 7 - Annual abundance estimates for selected megabenthic species at station 7, habitat type 1, for the period July, 1981 through July, 1984. Number photographic frames analyzed = 226, 148, 287, and 24 for 1981 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare).				Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)				
	1981	1982	1983	1984	
Mud Anemone	145 (78-212)	58 (12-104)	348 (212-484)	119 (52-290)	168 (20-315)
Rock Anemone	0 ---	0 ---	40 (6-74)	1071 (270-1872)	278 (0-900)
Starfish	25 (1-50)	222 (0-497)	622 (406-838)	893 (464-1322)	441 (0-900)
Cancer Crab	405 (264-545)	425 (270-579)	244 (156-332)	238 (53-529)	328 (209-447)
Galatheid Crab	1024 (703-1345)	39 (0-85)	0 ---	0 ---	266 (0-861)
Hermit Crab	32 (4-59)	10 (0-29)	20 (1-39)	25 (3-47)	22 (11-33)
Sea Scallop	13 (0-30)	0 ---	0 ---	0 ---	3 (0-11)
4-Spot Flounder	19 (0-40)	10 (0-29)	0 ---	0 ---	7 (0-18)
Greeneye	13 (0-30)	48 (6-90)	10 (0-30)	24 (2-46)	24 (3-44)
Blackbellied Rosefish	0 ---	0 ---	0 ---	0 ---	0 ---
White Hake	0 ---	0 ---	0 ---	0 ---	0 ---
Ocean Pout	6 (0-19)	0 ---	25 (3-47)	0 ---	8 (0-22)
Cunner	0 ---	0 ---	0 ---	0 ---	0 ---

Appendix Table 8 - Annual abundance estimates for selected megabenthic species at station 7, habitat type II, for the period July, 1981 through July, 1984. Number photographic frames analyzed = 397, 357, 191, and 198 for 1981 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)				Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)				
	1981	1982	1983	1984	
Mud Anemone	489 (378-601)	300 (212-389)	1055 (706-1404)	43 (4-83)	477 (0-979)
Rock Anemone	702 (487-917)	156 (91-221)	411 (255-567)	1061 (537-1584)	583 (125-1040)
Starfish	698 (579-825)	756 (623-889)	711 (544-878)	758 (589-926)	731 (695-767)
Cancer Crab	169 (119-219)	76 (41-111)	157 (93-221)	115 (61-170)	129 (79-179)
Hermit Crab	11 (0-23)	16 (0-32)	7 (0-22)	29 (1-57)	16 (4-27)
Galatheid Crab	4668 (3820-5517)	536 (481-592)	0 ---	0 ---	1301 (0-3959)
Sea Scallop	7 (0-17)	0 ---	0 ---	7 (0-21)	4 (0-8)
4-Spot Flounder	0 ---	4 (0-12)	0 ---	14 (0-34)	5 (0-12)
Greeneye	14 (0-32)	0 ---	7 (0-22)	0 ---	5 (0-13)
Blackbellied Rosefish	47 (22-72)	16 (0-32)	0 ---	0 ---	16 (0-42)
White Hake	0 ---	4 (0-12)	105 (38-172)	58 (18-97)	42 (0-100)
Ocean Pout	7 (0-17)	4 (0-12)	319 (274-364)	159 (90-228)	122 (0-298)
Cunner	0 ---	0 ---	0 ---	0 ---	0 ---

Appendix Table 9 - Annual abundance estimates for selected megabenthic species at station 7, habitat type III, for the period July, 1981 through July, 1984. Number photographic frames analyzed = 316, 325, 333, and 318 for 1981 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)				Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)				
	1981	1982	1983	1984	
Mud Anemone	23 (0-46)	44 (14-74)	30 (5-55)	5 (0-13)	26 (6-45)
Rock Anemone	4295 (3585-5005)	2435 (1961-2909)	3822 (3094-4550)	1851 (1400-2302)	3101 (1751-4451)
Starfish	696 (564-829)	1116 (956-1277)	390 (288-492)	921 (786-1056)	781 (414-1148)
Cancer Crab	448 (364-549)	185 (122-247)	223 (147-299)	193 (134-252)	262 (115-409)
Galatheid Crab	0 ---	92 (20-164)	34 (0-346)	9 (0-21)	34 (0-82)
Hermit Crab	0 ---	0 ---	17 (0-34)	5 (0-13)	6 (0-15)
Sea Scallop	0 ---	0 ---	0 ---	0 ---	0 ---
4-Spot Flounder	0 ---	0 ---	0 ---	0 ---	0 ---
Greeneye	0 ---	0 ---	0 ---	9 (0-21)	2 (0-8)
Blackbellied Rosefish	50 (21-79)	26 (5-47)	21 (2-40)	18 (0-35)	29 (12-46)
White Hake	258 (177-338)	272 (168-376)	292 (219-365)	984 (780-1187)	452 (36-869)
Ocean Pout	646 (521-772)	400 (300-500)	1866 (1622-2110)	3086 (2735-3437)	1500 (44-2956)
Cunner	68 (16-21)	35 (11-59)	52 (17-87)	38 (15-61)	48 (30-66)

Appendix Table 10 - Annual abundance estimates for selected megabenthic species at station 8, habitat type I, for period July, 1981 through July 1984. Number photographic frames analyzed = 1438, 663, 388, and 623 for 1981 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)				Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)				
	1981	1982	1983	1984	
Mud Anemone	73 (54-92)	185 (71-300)	15 (0-30)	21 (0-98)	74 (0-166)
Rock Anemone	0 ---	7 (0-14)	0 ---	0 ---	2 (0-6)
Cancer Crab	315 (279-351)	347 (285-409)	596 (514-678)	757 (297-1216)	504 (256-751)
Lobster	2 (0-6)	0 ---	0 ---	0 ---	1 (0-2)
Shrimp	2512 (2157-2866)	2659 (2281-3037)	784 (472-1096)	0 ---	1489 (0-3027)
Portunid Crab	12 (5-19)	26 (9-43)	7 (0-15)	14 (0-71)	15 (5-24)
Hermit Crab	1951 (1726-2176)	4570 (4129-5011)	390 (298-482)	294 (0-599)	1801 (0-4150)
Starfish	10 (1-20)	24 (10-38)	44 (21-67)	33 (18-48)	28 (11-45)
Skate	4 (0-8)	9 (0-17)	7 (0-15)	7 (0-47)	7 (4-9)
Goosefish	10 (1-20)	30 (13-47)	41 (21-61)	5 (0-38)	22 (2-41)
4-Spot Flounder	7 (2-12)	30 (13-47)	59 (31-87)	76 (0-211)	43 (7-79)
Greeneye	71 (42-99)	11 (1-20)	7 (0-15)	0 ---	22 (0-61)
Blackbellied Rosefish	8 (2-14)	2 (0-6)	7 (0-15)	2 (0-26)	5 (1-9)
Hagfish	112 (74-151)	82 (51-113)	96 (58-134)	16 (0-78)	77 (27-126)
Silver Hake	156 (119-193)	22 (0-11)	99 (64-134)	2 (0-26)	70 (0-153)
White Hake	4 (0-8)	4 (0-11)	0 ---	37 (0-145)	11 (0-32)

Appendix Table 11 - Annual abundance estimates for selected megabenthic species at station 8, habitat type III, for the period July, 1981 through July, 1984. Number photographic frames analyzed = 112, 663, 120, and 318 for 1981 to 1984 respectively.

Species	Density - Numbers Per 10,000 m ² (Hectare)				Grand Mean 90% Conf. Limits)
	(95%) Confidence Limits)				
	1981	1982	1983	1984	
Mud Anemone	459 (298-621)	179 (79-278)	536 (374-698)	23 (3-56)	299 (17-581)
Rock Anemone	38 (0-95)	336 (200-472)	202 (126-278)	245 (160-330)	205 (59-352)
Cancer Crab	587 (395-778)	305 (193-417)	429 (300-558)	2830 (2578-3088)	1038 (0-2450)
Lobster	26 (0-61)	0 ---	0 ---	9 (0-21)	9 (0-23)
Shrimp	64 (15-113)	137 (39-234)	12 (0-31)	0 ---	53 (0-127)
Portunid Crab	0 ---	42 (1-83)	36 (2-70)	54 (22-86)	33 (6-60)
Hermit Crab	295 (79-511)	179 (52-305)	119 (54-184)	31 (8-55)	156 (26-286)
Starfish	64 (8-119)	221 (123-318)	298 (194-402)	18 (0-35)	150 (0-305)
Skate	13 (0-38)	10 (0-22)	12 (0-31)	0 ---	9 (2-16)
Goosefish	26 (0-61)	0 ---	48 (9-87)	0 ---	19 (0-46)
4-Spot Flounder	0 ---	11 (0-31)	24 (0-52)	23 (3-56)	15 (1-28)
Greeneye	0 ---	0 ---	0 ---	0 ---	0 ---
Blackbellied Rosefish	26 (0-61)	32 (0-67)	131 (69-193)	27 (6-47)	54 (0-114)
Hagfish	0 ---	21 (0-50)	12 (0-31)	14 (0-29)	12 (1-22)
Silver Hake	561 (399-723)	63 (13-113)	71 (24-118)	54 (15-93)	187 (0-481)
White Hake	51 (0-122)	11 (0-31)	12 (0-31)	58 (3-113)	33 (4-62)

Appendix Table 12 - Annual abundance estimates for selected megabenthic species at station 9, habitat type I, for the period July 1982, through July 1984. Number photographic frames analyzed = 695, 755, and 695 for 1982 to 1984 respectively.

Species	Density - Numbers per 10,000 m ² (Hectare)			Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)			
	1982	1983	1984	
Mud Anemone	0 ---	0 ---	0 ---	0 ---
Sea Pens	4201 (3853-4550)	3527 (3063-3991)	3355 (3005-3705)	3694 (2941-4448)
Cancer Crab	197 (157-237)	263 (219-307)	70 (25-115)	177 (11-342)
Lobster	0 ---	0 ---	0 ---	0 ---
Shrimp	6 (0-18)	208 (134-282)	0 ---	71 (0-271)
Hermit Crab	1484 (1358-1610)	747 (653-841)	904 (754-1154)	1045 (391-1699)
Galatheid Crab	84 (42-127)	255 (196-1114)	29 (4-54)	123 (0-321)
Scallop	0 ---	0 ---	0 ---	0 ---
Starfish	41 (23-59)	655 (527-783)	35 (4-66)	244 (0-844)
4-Spot Flounder	60 (38-82)	51 (35-67)	12 (0-35)	41 (0-84)
Goosefish	6 (0-13)	38 (24-52)	0 ---	15 (0-49)
Greeneye	4 (0-12)	106 (75-137)	72 (2-142)	61 (0-148)
Blackbellied Rosefish	14 (4-25)	40 (23-57)	41 (21-61)	32 (6-57)
Silver Hake	12 (3-22)	19 (9-29)	10 (0-28)	14 (6-22)
Skate	0 ---	0 ---	2 (0-11)	1 (0-3)

Appendix Table 13 - Annual abundance estimates for selected megabenthic species at station 9, habitat type III, for the period July, 1982 through July, 1984. Number photographic frames analyzed = 0, 45, and 259 for 1982 to 1984 respectively.

Species	Density - Numbers per 10,000 m ² (Hectare)			Grand Mean (90% Conf. Limits)
	(95% Confidence Limits)			
	1982	1983	1984	
Mud Anemone	0 ---	0 ---	0 ---	0 ---
Sea Pens	0 ---	1397 (690-2104)	629 (579-679)	1013 (0-3438)
Cancer Crab	0 ---	95 (7-183)	6 (0-18)	51 (0-331)
Lobster	0 ---	635 (562-708)	6 (0-18)	321 (0-2306)
Shrimp	0 ---	0 ---	0 ---	0 ---
Hermit Crab	0 ---	159 (25-293)	22 (0-47)	91 (0-523)
Galatheid Crab	0 ---	4444 (3441-5447)	287 (187-397)	2366 (0-15489)
Starfish	0 ---	190 (0-503)	28 (0-59)	109 (0-620)
Greeneye	0 ---	286 (43-529)	66 (0-196)	176 (0-871)
Blackbellied Rosefish	0 ---	857 (583-1131)	794 (534-1054)	826 (816-835)
Conger Eel	0 ---	32 (0-84)	6 (0-18)	19 (0-46)

Appendix Table 14. Concentrations of trace metals analyzed from substrate and faunal (cancer crab, sea scallop) samples collected at monitoring stations II and III, Georges Bank. Tissue samples from 4 to 20 individuals were combined, by species, for a composite sample. * - No data available. N.D. means non-detectable, concentrations less than 0.01 ppm (ug/g wet weight).

Type of Sample	Station	Trace Metal Concentrations (ppm or ug/g)							
		Ba	Cd	Cu	Cr	Hg	Pb	Zn	
		1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	
Sediment	2	40.3-8.1 52.3-20.0	0.02-0.19 0.28- .14	1.03-1.08 25.00-3.06	3.10-4.23 1.34-5.66	N.D. - 0.34 N.D. - N.D.	0.40-5.77 2.28-3.88	40.50- 9.12 8.95-29.70	
Sediment	3	39.4- 3.15 8.4-16.90	0.01-0.12 0.87-0.06	0.25-62.1 1.90- 0.58	3.80-5.06 3.24-2.99	N.D. - 0.23 0.15 - N.D.	0.38-2.72 1.59-2.98	1.60- 5.25 2.64-4.71	
Crab Muscle (Chaeiliped)	2	0.11-0.12 <1.0-0.09	0.49-0.26 0.18-0.53	11.80-14.70 12.00- 9.50	0.18-0.04 0.28-N.D.	0.60 - 0.88 0.10 - 0.90	0.94 - 0.18 0.83 - 0.55	102.60-44 89.50-79.14	
Crab Muscle (Chaeiliped)	3	0.13-0.25 N.D.-0.30	0.50-0.03 0.13-0.46	1.09-16.25 5.3 - 7.71	0.22-0.04 1.49-0.30	0.05 - 0.95 0.22 - 0.16	0.08 - 0.04 0.14 - 0.03	84.80-69.17 84.60-71.06	
Scallop viscera	2	0.59-0.10 * -0.30	77.0-29.65 * -64.96	2.22-12.06 * -10.77	0.60-1.15 * -1.07	0.02 - 0.10 * - N.D.	0.38 - 0.06 * - 0.44	12.90-11.97 * - 13.71	
Scallop viscera	3	0.16-0.16 * - *	41.7-75 * - *	2.52-17.48 * - *	0.24-0.66 * - *	0.01 - 0.22 * - *	0.27 - 0.09 * - *	24.20-13.11 * - *	
Scallop muscle	2	0.17-0.39 <1.0-0.41	1.92-7.56 0.53-5.66	0.25-10.10 0.40- 3.98	0.55-0.20 0.31-0.44	0.02 - 0.40 N.D. - 0.09	0.04 - 0.06 0.27 - N.D.	11.30- 9.14 N.D. - 12.07	
Scallop muscle	3	0.12-0.21 5.3 - *	0.50-1.54 1.32- *	1.30-8.93 0.40- *	0.39-0.02 0.59- *	0.01 - 0.27 0.06 - *	1.74 - 0.42 0.08 - *	13.70-23.82 25.00 - *	

Appendix Table 15. Concentrations of trace metals analyzed from substrate and faunal (cancer crab, lobster, tilefish) samples collected at monitoring stations V and VI, Lydonia Canyon. * - No data available. N.D. means non-detectable, concentrations less than .01 ppm (ug/g wet weight).

Type of Sample	Station	Trace metal concentrations (ppm or ug/g)									
		Ba	Cd	Cu	Cr	Hg	Pb	Zn			
		1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983	1980-1981 1982-1983			
Sediment	5	58.9-8.27 21.9-44.8	0.07 - 0.24 0.24 - 0.09	2.15- 1.57 1.40- 1.66	11.3 - 7.28 3.06- 5.44	N.D. - 0.40 0.01 - N.D.	0.52 - 4.33 2.03 - 1.58	13.6 - 10.94 3.58- 7.08			
Sediment	6	* - *	* - *	* - *	* - *	* - *	* - *	* - *			
Crab muscle (Chaeliped)	5	0.08-0.04 N.D.-0.06	0.33 - 0.07 0.50 - 0.09	7.70-15.18 6.33-10.04	0.47- 0.16 0.10- 0.15	0.011- 0.51 0.09 - 0.43	0.06 - 0.14 0.18 - 0.22	77.0- 73.68 69.5- 70.66			
Crab muscle (Chaeliped)	6	0.06-0.09 0.15-N.D.	1.18 - 0.05 0.75 - 1.32	9.70-15.95 10.43-13.33	0.07- N.D. N.D.- N.D.	0.006- 0.33 N.D. - 0.46	0.78 - 0.02 0.63 - 0.49	87.1- 63.92 75.6- 77.94			
Crab (Hepa- topancreas)	6	0.50- * * - *	17.3 - * * - *	40.8 - * * - *	0.92 - * * - *	0.064- * * - *	0.23 - * * - *	56.5- 0.92 * - *			
Lobster muscle (Chaeliped)	6	0.07-0.18 N.D.-0.30	0.18 - 0.01 0.15 - 0.09	7.18-22.82 10.46-18.74	0.05- 0.02 N.D.- 0.07	0.22 - 0.29 0.60 - 0.15	0.05 - 0.15 N.D. - 0.40	37.0- 19.05 40.6- 23.91			
Lobster muscle (tail)	6	0.12-0.23 0.30-0.09	0.12 - 0.04 0.16 - N.D.	10.6 - 13.68 12.01- 7.88	0.06- 0.17 N.D.- 0.11	0.270- 0.25 0.31 - 0.19	0.07 - 0.69 0.68 - 0.43	25.9- 31.01 28.6- 33.33			
Lobster (Hepa- topancreas)	6	0.04- * * - *	19.5 - * * - *	18.3 - * * - *	0.07- * * - *	0.087- * * - *	0.62 - * * - *	37.3- * * - *			
Lobster eggs (Mature)	5	0.23- * 0.27- *	0.13 - * 0.20 - *	62.0 - * 43.9 - *	0.24- * 0.33- *	0.035- * 0.088- *	0.07 - * N.D. - *	39.8- * 41.5- *			
Tilefish	6	0.21-0.18 0.09-0.30	0.002-0.002 N.D.-0.007	1.79- 0.45 2.04- 0.93	0.09- N.D. N.D.- 1.33	0.02 - 0.29 0.15 - N.D.	0.90 - 0.06 1.35 - 0.73	3.7 - 4.75 5.04- 2.38			
Tilefish	6	0.25-0.23 0.19-0.22	N.D.-N.D. 0.009-0.010	2.43- * 1.96- 1.04	N.D.- 0.46 N.D.- 0.03	0.30 - 0.15 0.19 - 0.26	1.66 - 1.04 0.91 - 0.07	3.91- 6.88 4.40- 3.87			

STUDIES ON TILEFISH FISHERY BIOLOGY,
ECOLOGY AND BIOEROSION ON THE MIDDLE ATLANTIC
AND SOUTHERN NEW ENGLAND CONTINENTAL SHELF

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ABSTRACT

Manned submersibles were used in the vicinity of submarine canyons of southern New England and the mid-Atlantic Bight during the summers of 1979 through 1984 to evaluate the performance of commercial bottom longline gear, document the abundance and distribution of tilefish shelters and define the ocean floor fauna associated with the tilefish shelters. Time-lapse photography documented tilefish behavior relative to the shelters. Coordinated submersible, sidescan sonar and seismic profiling operations were conducted to define the role of bioerosion by tilefish in shaping seafloor topography. Sidescan sonographs showed individual tilefish burrows whose distribution were highly contagious. At Hudson Canyon, tilefish had created an 800 km² area of rough topography through bioerosion which has probably been occurring over the past 12-13,000 years.

INTRODUCTION

Because of the major ecological and economic significance of tilefish, we have studied them since 1979 using manned submersibles. Our studies have provided information relevant to the rational exploitation of their valuable fisheries, and discovered their important role in sea floor processes. In this paper we summarize the results of these in situ studies; for further details refer to the original papers on commercial fishing gear performance (Grimes et al. 1982); behavior, community structure and habitat (Able et al. 1983; Grimes et al. 1986); the role of tilefish bioerosion in shaping bottom topography (Twichell et al. 1985); and use of sidescan sonar as a fishery tool (Able et al. in prep.).

Tilefish, Lopholatilus chamaeleonticeps, are large (to 120 cm and 27 kg) demersal branchiostegid fishes found along the edge of the continental shelf in 80-540 m depths from Nova Scotia to Surinam (Dooley 1978; Markle et al. 1980). In the Middle Atlantic Bight and Southern New England waters they have usually been found from 80-240 m. This species is long lived and slow growing, reaching at

least 112 cm FL and 35 years (Turner et al. 1983). Batch spawning occurs during summer, with females producing pelagic eggs; reproduction is socially mediated (Grimes et al. in prep.). Tilefish are benthic carnivores, the diet consisting mostly of crustaceans and fishes and secondarily of polychaetes and echinoderms (Turner and Freeman in prep.). In addition, the investigations we summarize here suggest that tilefish are "keystone" species, critical to the organization and maintenance of their community.

Commercial exploitation of the Middle Atlantic-Southern New England tilefish stock (Katz et al. 1983) began in 1915, and landings have been reported nearly every year since. Annual landings have fluctuated between a peak of 4,500 metric tons (t) in 1916 to 1 t for several years since. Landings have increased dramatically since the 1970's, due to the development of an important longline fishery centered in New York and New Jersey. Landings from 1977-1982 (2,000, 3,400, 3,800, 3,600, 3,200 and 1,900 t, respectively) exceeded all previous years for which information is available except 1916 (Freeman and Turner 1977; U.S. Dept. Comm. 1980 a-c; Christensen pers. comm.). Tilefish have been the most valuable finfish fishery in New Jersey and New York in most years since 1978.

METHODS AND PROCEDURES

Study sites and submersibles used

We conducted a series of submersible cruises along the east coast of the U.S. (Fig. 1) during the summers of 1979-1984 (Table 1). In 1979 we used the two man submersible Nekton Gamma, a 4.9 m long vessel that could operate to a depth of 300 m. Support for Nekton Gamma was provided by the R/V Atlantic Twin. All other dives reported here were conducted with the Harbor Branch Oceanographic Institution's four-man submersible Johnson-Sea-Link, operated from the support ship R/V Johnson.

Habitat, behavior and community structure

Dives were made along straight line transects (across or along depth contours), or in accordion shaped tracks for more detailed mapping (see Grimes et al. 1986). On other dives, when specific tasks (behavior observations, burrow measurement and dissection, etc.) were planned, the submersible moved very little. During a typical dive, physical (bottom temperature, depth, topography, visibility, current speed and direction and substrate type) and biological (tilefish abundance, size, sex, behavior, burrow number and dimensions, and associated fish and macroinvertebrates) parameters were recorded on audio tapes. Photographs were taken with one or two externally mounted 35 mm cameras and a bow-mounted video camera with the recorder located in the submersible.

Estimates of tilefish length, habitat dimensions and densities of associated fish and macroinvertebrates were made from 35 mm photographs projected onto grids of known dimensions. The grids were

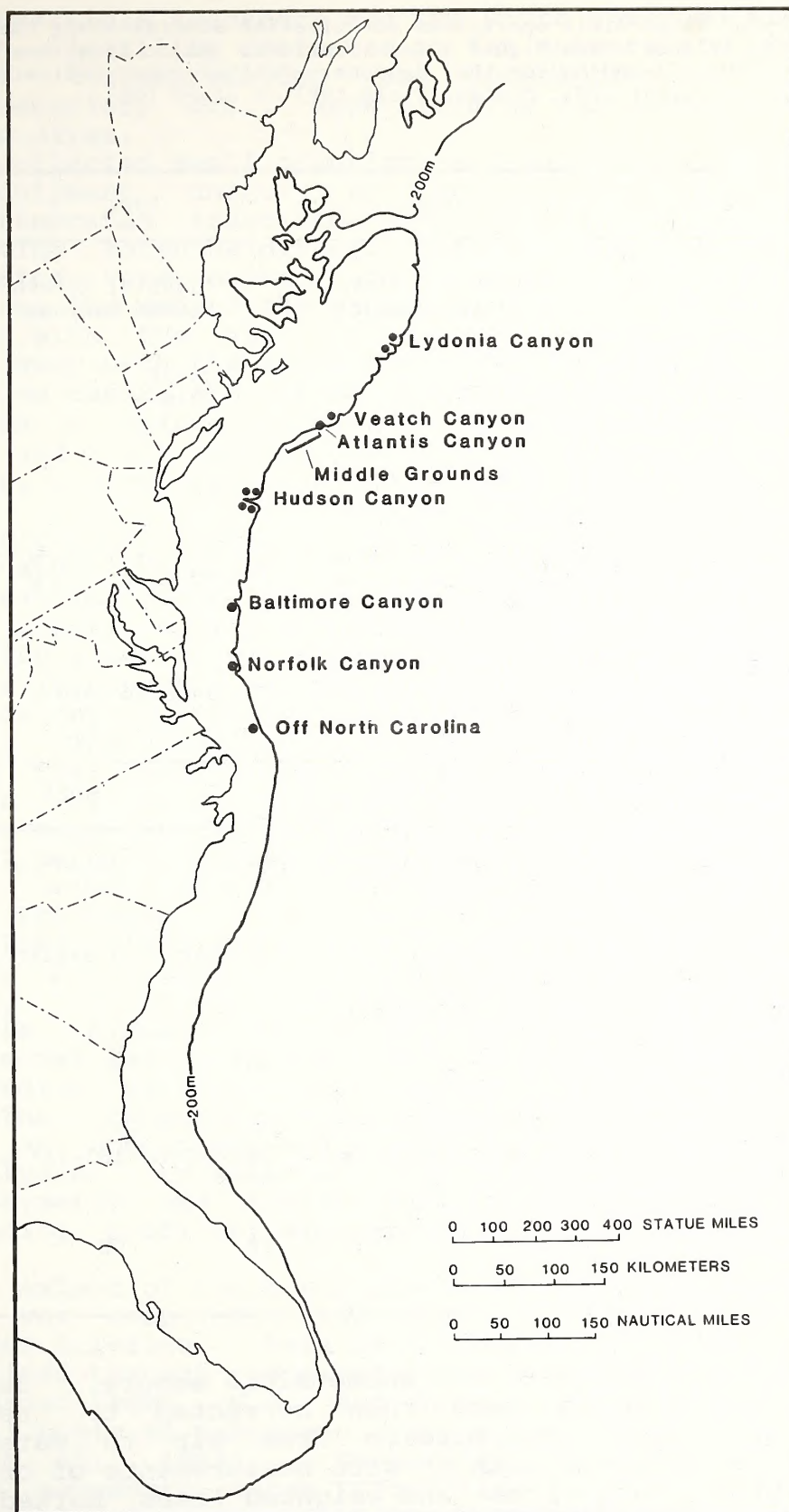


Figure 1. Map of U.S. east coast showing study sites.

Table 1. Summary of submersible operations for tilefish studies along the east coast of the U.S. during 1979-84. See Figure 1 for locations. Major locations include Lydonia (LC), Veatch (VC) and Hudson (HC) Canyons. Habitat types indicated as vertical burrow (VB), Pueblo habitat (PH), boulder field (BF) or other (OH).

	1979	1980		1981		1982
Locations	Hudson Canyon	Lydonia, Veatch Hudson Canyons		Lydonia, Veatch Hudson Canyons		Hudson Canyon
Cruise dates	23-27 August	6-18 August		23-28 July		22-30 July
Number of dives	12	12		12		9
Depth range of observations	85-299 m	LC = 139-192 m VC = 117-229 m HC = 146-156 m		LC = 134-268 m VC = 122-213 m HC = 144-241		129-227 m
Types of habitats observed	VB	LC = VB, PH, BF VC = VB, PV, BF HC = VB		same as 1980		VB
	1983			1984		
Locations	Hudson Canyon	Baltimore Canyon	Norfolk Canyon	Middle Grounds	Atlantis Canyon	Veatch Canyon
Cruise dates	15-16 August	17 August	18 August	29 July-	3 August	4 August
Number of dives	4	2	2	10	2	1
Depth range of observations	119-175 m	204-253 m	175-247 m	102-243 m	183-337 m	130-132 m
Types of habitats observed	VB	OH	OH	VB	OH	VB

originally photographed with the submersible ashore. Estimates for the above measurements were then corrected to reflect the differences in light transmission from air to water. These estimates were validated with in situ measurements of objects from Johnson-Sea-Link using rods and weighted lines marked in known increments and checked against photographic estimates of the same objects. Density estimates for tilefish and burrow abundance were determined using the numbers of fish and habitats seen, the length

of the submersible transects and the width observed along the tracks (based on visibility estimates by the submersible pilot and the observer). Interpretation and description of habitat types, tilefish behavior, etc., were aided by reviewing video tapes made during the dives.

We collected small organisms and made additional observations using equipment unique to Johnson-Sea-Link. Fishes and macroinvertebrates associated with tilefish habitat were collected by injecting rotenone directly into burrows. Fishes and macroinvertebrates were sucked into a collecting box through a nozzle attached to the end of the manipulator arm. Tilefish burrows were dissected with the jaws of the manipulator arm or by blowing sediments away with the submersible bow thruster.

A 35 mm camera and strobe, controlled by an intervalometer, was mounted on a tripod and used to take time-lapse photographs of tilefish and their burrows near Hudson Canyon. Photographs were taken every 2.0 minutes over a 24 hour period.

Fishing Gear Performance

This study was conducted near Hudson Submarine Canyon (Fig. 1) in cooperation with the commercial longline vessel Lori-L from Barnegat Light, N.J. While longlines were being set, hooks were marked with a series of colored ribbons and numbered plastic tags. This made it possible to coordinate our in situ observations with those made by colleagues and the Lori-L crew as the gear was retrieved. The longline was observed using Nekton Gamma. To determine the importance of bait predation we calculated the percentage of hooks observed with predators and without baits at successive time intervals (High 1980). See Grimes et al. (1982) for additional details of this procedure.

Sea Floor Processes

In 1982, 1983 and 1984 we investigated the role of sea floor bioerosion by tilefish in the formation of an area of rough topography around Hudson Canyon. We employed coordinated submersible, sidescan sonar and subbottom profiling operations. Sidescan sonar images (sonographs), 3.5 kHz subbottom profiles and echo sounding profiles were collected from R/V Johnson between dives. The Johnson-Sea-Link was used to "ground truth" features observed on sonographs and to collect sediment samples for grain size analysis. In selected areas we constructed detailed maps of the bathymetry and burrow distribution using closely spaced echo sounding profiles, sidescan sonographs, and many submersible dives.

The extent of rough sea floor topography mapped with seismic profiles was compared to the spatial distribution of commercial fishing for tilefish. Data on the commercial fishery for tilefish was obtained through cooperation with commercial longline fisherman from Barnegat Light, N.J. and Montauk, N.Y. during a study of the biological basis of management of the fishery (Grimes et al. 1980; Turner et al. 1983). Cooperating fishermen maintained logs providing necessary catch information (e.g., catch location and date, and amount of gear fished). We used these data to produce a point distribution map of fishing locations (Robertson 1967; Cesney 1972) for comparison to the geological data.

RESULTS AND DISCUSSION

Performance of Commercial Fishing Gear

We made two daytime dives in August 1979 to observe baited longlines (Grimes et al. 1982) and saw 42 hooked fish; most were alive and in good condition. Only four tilefish were dead; two had swallowed the bait and were hooked internally and two fish were bitten off just behind the operculum, presumably by sharks (probably the dusky shark, Carcharhinus obscurus).

The burrowing behavior of tilefish may have caused loss of catch. Seven (17%) of the 42 tilefish observed on marked longlines on the bottom were not accounted for on the Lori-L. It is likely that hooks were pulled free from fish partially in their burrows, because we observed several attempts by hooked fish to enter burrows.

Apparently baited longlines attracted tilefish from a wider area than just the immediate vicinity of the longline. During five dives made on tilefish grounds (but not along baited longlines) to investigate behavior and ecology there was a strong positive correlation ($r = 0.91$) between the number of tilefish seen and the number of burrows encountered; few tilefish were away from burrows (see Fig. 1 in Grimes et al. 1982). Along a baited longline we observed many more hooked tilefish (42) than would have been predicted from the number of burrows sighted (3), which suggested that tilefish foraged some distance away from their burrows to take a baited hook.

Benthic invertebrate predators on bait were an important factor affecting catch and optimum soak time. Starfish (Astropecten sp.) accounted for 70% of bait predators observed; the crabs Cancer sp. and Acanthocarpus alexandri accounted for 26% and 6%, respectively. Predation began soon after the longline was set and increased linearly with soak time until all hooks observed were preyed upon after 190 minutes (Fig. 2). Complete removal of bait took longer; all hooks had bait at 78 minutes, but the percent of hooks with bait began to decrease, falling to 70% (excluding hooks with tilefish) after 190 minutes. After 8 hours all hooks were bare (Fig. 2).

We could not determine optimum soak time very precisely. No fish were caught during the first 60 minutes of the longline set, so the minimum soak time may be around 2 hours. When 42 tilefish were caught, all baits were gone after 8 hours (and 90% gone after 7 hours), which gives the maximum useful time.

Most of this assessment would not have been possible without the submersible. Information on burrowing behavior and the resulting catch loss, foraging behavior and its relevance to the area fished by longlines, and the identification of bait predators and the predation rate could only have been acquired by traversing a baited longline with a submersible. The presumed rate of bait loss from predation (because bait predators could not be directly observed) and the rate of catch loss from predation could have been determined from a commercial fishing vessel, the former only with repeated longline settings and retrievals at time intervals. Repeated longline settings would have required chartering the vessel because normal fishing operations would have been precluded. We

believe these factors made the submersible a particularly effective and efficient sampling platform.

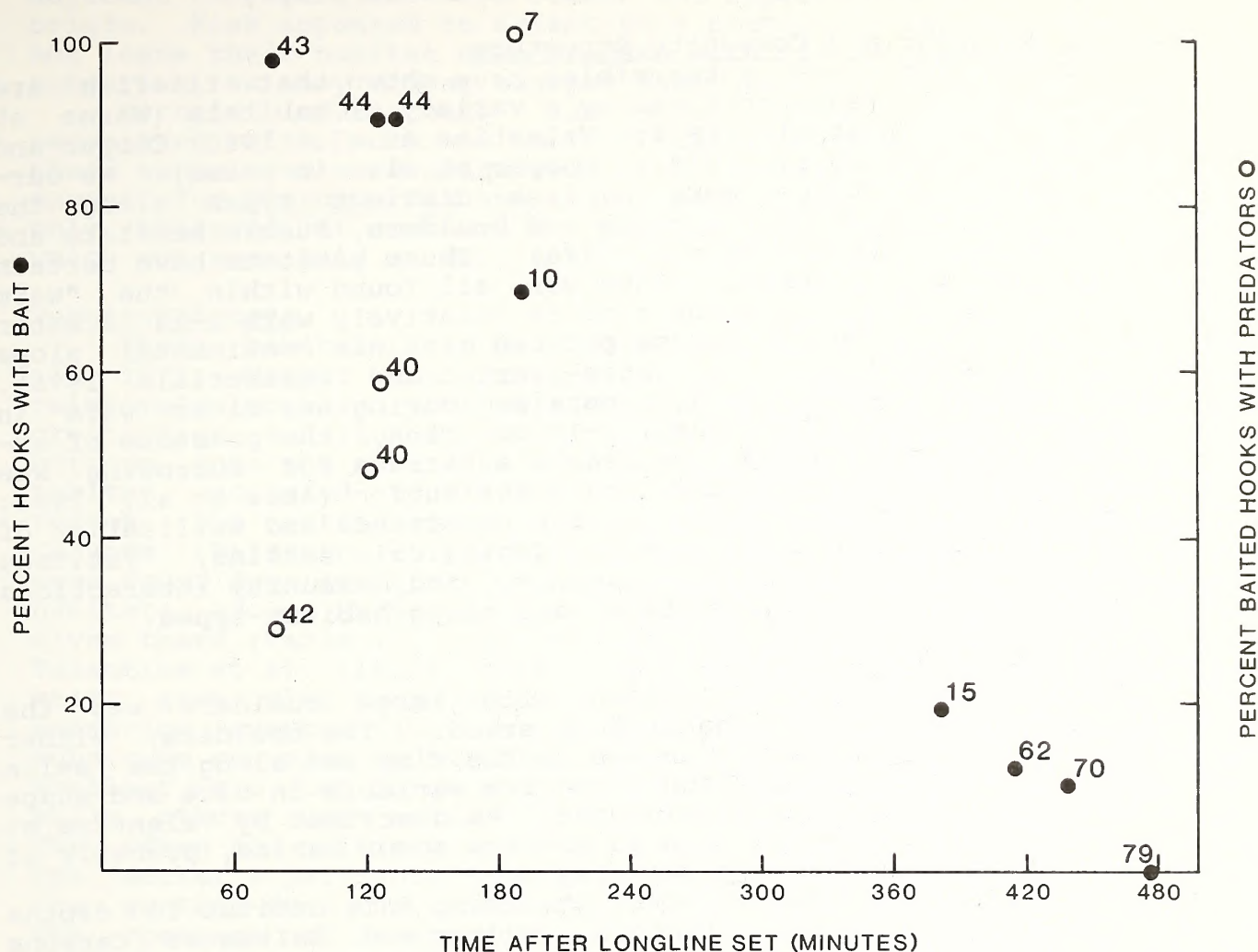


Figure 2. Predation on baited longline hooks by benthic invertebrates and rate of bait loss. Numbers of hooks observed between successive time intervals are shown above data points (from Grimes et al. 1982).

Sidescan Sonar As a Fishery Tool

Using sidescan sonar in conjunction with submersible operations we determined that it was possible to identify individual tilefish burrows on sidescan sonographs (see subsequent Sea Floor Processes section). This finding suggested to us that high resolution sidescan sonar (100 kHz) might have more general utility as a fishery tool. Because individual burrows were identified it could be used to find new tilefish grounds, and determine abundance in unfished areas. It may also be possible to identify critical habitats of other fishery resources as well, for example boulder and Pueblo habitats and rock outcroppings, etc. We conducted further

studies in 1984 to establish if some of these other habitats were identifiable with sidescan sonar, and also determined that the lower size limit of burrows that could be resolved on relatively flat bottom was about 0.5 m diameter (Able et al. in prep.).

Habitat, Behavior and Community Structure

Observations from submersibles have shown that tilefish are shelter seeking fishes that occupy a variety of habitats (Warme et al. 1977; Uzmann et al. 1978; Valentine et al. 1980; Cooper and Uzmann 1980; Able et al. 1982; Cooper et al. in press). We currently recognize three more or less distinct types along the northeast coast of the U.S.: rocks and boulders, Pueblo habitats and vertical burrows (Grimes et al. 1986). These habitats have certain characteristics in common. They were all found within the "warm belt" (Verrill 1882), a narrow zone of relatively warm 9-14° C water which represents the interface between distinct continental slope and continental shelf water masses (Christ and Chamberlain 1976). Temperature and salinity data obtained during our dives were in agreement (Grimes et al. 1986). In addition, the presence of exposed clay that provided a malleable substrate for burrowing was critical to burrow construction and distribution (Able et al. 1983; Twichell et al. 1985). However, the occurrence and utilization of the different habitats varied with geological setting, latitude and season. Fish behavior, residency, and community interactions and structure differed both between and among habitat types.

Boulders and Rocks

The association of tilefish with large boulders was the simplest type of tilefish habitat observed. The boulders, either singly or in clumps, were observed on the rims and along the walls of submarine canyons. The boulders were variable in size and shape and ranged from 0.3 - 5 m in diameter. As described by Valentine et al. (1980) boulders were often in shallow scour basins, probably of combined physical and biological origin.

Tilefish have been observed utilizing this habitat in depths from 149-242 m in Veatch, Lydonia, Hudson and Baltimore Canyons (Able et al. 1982; Grimes et al. 1986) and in Oceanographer Canyon (Valentine et al. 1980). This habitat for tilefish appears to be more common in the northern canyons which were closer to the late Pleistocene glaciers, the source of these boulders (Valentine et al. 1980; Cooper et al. In press).

Tilefish evidently use boulders for shelter. Typically, tilefish rested motionless against or, if possible, under a portion of a boulder. In most instances a single adult tilefish was observed at a boulder, but on occasion as many as three could be seen simultaneously. Utilization of boulder habitats appears to be random and temporary. On several occasions we chased tilefish away from boulders with the submersible and followed them to note their subsequent choice of habitats. Fish stopped at various other boulders and showed no inclination to return to the original boulder. Furthermore, on later dives to the same boulder we could not establish that the same fish was present.

We observed four tilefish occupying excavations under rock slabs among anemone fields at a dive site along the southwest wall of Baltimore Canyon. Numerous rock slabs about 1 x 2 m, with their

axes at varying angles to the slope, covered the bottom for a distance of over 150 m on a steeply sloping (30°) canyon wall from 204 to 253 m depth. Excavations in the grey sediment under and adjacent to rock slabs were common and appeared to be of biological origin. Fish appeared to orient to a particular habitat; they would not leave their habitat when prodded with the manipulator arm of the submarine, as they did at boulder habitats.

Certain crustaceans and other fishes were commonly associated with rock and boulder habitats (Table 2). Most of these associates were ubiquitous with tilefish in these habitats, except for Macrozoarces americanus and Brosme brosme which were only observed at southern New England sites and Sebastes sp. which was seen only at Baltimore and Norfolk Canyons.

Pueblo Habitats

These habitats have been illustrated and described (Warme et al. 1977; Cooper and Uzmann 1977, 1980) by the former as "a relatively localized area of submarine canyon wall where megabenthic crustaceans and finfish have intensively bioeroded depressions and borings into the substrate and have occupied these sites." Pueblo habitat, occupied by tilefish, was commonly observed in Lydonia, Veatch (the latter also by Warme et al. 1977) and Oceanographer Canyons (Valentine et al. 1980). During our dives these habitats were found from 170 to 245 m depth. We have never observed Pueblo habitats around Hudson Canyon, even though we have made many more dives there (Table 1). We observed, as did Warme et al. (1977) and Valentine et al. (1980), that Pueblo habitats always occurred in the stiff grey clay found as outcrops along the walls of many of the submarine canyons in the study area. The excavations in the substrate occupied by tilefish were variable in shape and size. The smallest were just large enough to admit the girth of the tilefish, while others were as much as 1 m wide by 3 m long, and 1 m deep. They often had multiple openings into a single layer space (grotto). Dye marker experiments revealed that large and small openings into the grottos from the substrate surface were common and numerous. The openings not constructed by tilefish result from the burrowing activity of several associated species (Table 2).

The behavior of tilefish occupying Pueblo habitats was similar to those in excavations under rock slabs, but different from boulders. When approached by the submersible, tilefish always entered head first, and then usually pressed themselves against the back of the grotto and remained motionless. Exits from the grotto were tail first or head first. Following acclimation to the submersible, tilefish would leave the grotto but remained in the immediate vicinity (within 2-3 m). If disturbed, they moved directly back into the grotto and became motionless again.

Individual tilefish may be long-term residents of the same Pueblo habitat. We independently identified (using fish size and various body scars and marks) the same two adult tilefish at the same location approximately one year apart.

Habitat very similar to Pueblo habitat was observed on the north wall of Norfolk Canyon between 175 and 247 m. This habitat consisted of extensive, heavily bioeroded areas of stiff grey clay that was topographically complex, with several large clay blocks thrust up above the substrate with vertical walls and overhangs 25 m

Table 2. Fishes and crustaceans observed at various tilefish habitats along the northeast coast of the U.S. during 1980-1983. Each species was observed every year (see Table 1) unless otherwise noted. HC = Hudson Canyon, VC = Veatch Canyon, LC = Lydonia Canyon, BC = Baltimore Canyon, and NC = Norfolk Canyon (from Grimes et al. 1986).

Species	Boulders and rocks	Pueblo habitats	Vertical burrows
Crustaceans			
<u>Munida</u> sp. ^a	VC, LC	VC, LC	VC, LC
<u>Munida longipes</u>	BC	NC	--
<u>Cancer</u> sp.	VC, LC	VC, LC	VC, LC, HC
<u>Acanthocarpus alexandria</u>	--	--	HC
<u>Homarus americanus</u>	VC, LC	VC, LC	VC, LC, HC
<u>Bathynectes superba</u>	BC	NC	HC
<u>goneplacid</u> (possibly <u>Chacellus filiformis</u>)	--	--	VC, HC
Fishes			
<u>Conger oceanicus</u>	VC, LC	VC, LC	VC, HC
<u>Macrozoarces americanus</u>	VC, LC	VC, LC	--
<u>Brosme brosme</u>	VC, LC	--	--
<u>Anthias nicholsi</u>	VC, LC, BC	VC, LC, NC	VC, LC, HC
<u>Helicolenus dactylopterus</u>	VC, LC, BC	VC, LC, NC	VC, LC, HC
<u>Sebastes</u> sp.	VC	NC	--
<u>Urophycis</u> sp.	--	VC	HC
<u>Laemonema</u> sp. (possibly <u>L. barbatum</u>)	--	NC	--

a. Three species have been identified from collected specimens: M. iris, M. valida, and M. forceps. However, it is not possible to distinguish them from submersible sightings or photographs.

high. Tilefish were observed inhabiting the largest of the grotto-like excavations (up to 2 m greatest distance across the opening).

Although these Norfolk Canyon habitats were physically very similar to Pueblo habitats, they were quite different biologically (Table 2). Numerous anemones (Halcurias pilatus) living attached to the burrowed clay characterized the community in Norfolk Canyon. Anthias nicholsi was common, along with Sebastes sp., the galatheid crab Munida longipes and the portunid crab Bathynectes superba.

Vertical Burrows

We believe vertical burrows are the primary habitats of tilefish in the Middle Atlantic and southern New England area (Able et al. 1982; Grimes et al. 1986). Vertical burrows, especially larger ones, were funnel-shaped and extensively secondarily burrowed by associated species along the upper margin. The larger secondary burrows located at the burrow margin were connected to the main burrow shaft. Burrows were contagiously distributed. By compiling the frequency distributions of distances between all adjacent

burrows observed on transect dives we determined that 27% of all burrows seen at Hudson Canyon were less than 20 m apart (Grimes et al. 1986).

Burrows were observed over greater depth ranges around Hudson Canyon (120-225 m) and at the Middle Grounds (102-243 m), than at the two more northern submarine canyons (Veatch Canyon 120-165 m; Lydonia Canyon 125-183 m). At Veatch Canyon and Lydonia Canyons, where boulder and Pueblo habitats also occurred, vertical burrows were in shallower water. Largest burrows were observed at Hudson Canyon (Table 3; mean depth = 1.7 m, range = 1.25-2.3 m, n = 6). Burrows estimated to be up to 5.0 m in diameter were observed but not measured because they were too large to appear entirely within

Table 3. Diameter (mean and range in m) of tilefish burrows near submarine canyons in the Mid-Atlantic-Southern New England area; n = number of burrows measured (from Grimes et al. in press).

Study Area	1980	1981	All
Hudson Canyon	1.57 (0.8-3.5) n = 26	1.6 (0.3-3.0) n = 25	1.6 (0.3-3.5)* n = 51
Veatch Canyon	0.89 (0.4-2.0) n = 20	0.84 (0.3-1.5) n = 20	0.88 (0.3-2.0)* n = 40
Lydonia Canyon	-	0.88 (0.5-1.2) n = 6	0.88 (0.5-1.2) n = 6

*Mean burrow diameters for Hudson and Veatch canyons are significantly different [$t = 6.73$, $t(.05) = 0.99$].

the photographic field of view. Burrows were generally smaller (Table 3), less secondarily bioeroded, less funnel shaped and less dense (Table 4) at dive locations north of Hudson Canyon. In fact, burrows at Hudson Canyon were on the average twice as large (upper cone diameter), over eight times more dense and much more complex than burrows at Lydonia Canyon. We believe that geographic differences in burrow habitats indicated that habitats at the more northern dive locations were less temporally stable. The temporal instability probably resulted from the greater seasonal variations in bottom temperatures at more northern dive locations (Grimes et al. 1986).

We hypothesized that the conical upper portion of larger burrows results from the combined activity of tilefish and the associated species that inhabit burrow margins. Galatheid crabs, which inhabit the smallest secondary burrows in burrow cones, displace sediments into burrows and these sediments are forced out

Table 4. Density (mean and range) of tilefish burrows per km² near submarine canyons of the Mid-Atlantic-Southern New England area based on submersible transects; n = number of transects (from Grimes et al. in press).

Study area	1980	1981	1982	All
Hudson Canyon	1815 (952-2434) n = 4	1239 (1011-1548) n = 2	1132 (592-1646) n = 6	1234 (592-2434) n = 12
Veatch Canyon	958 (119-1429) n = 4	772 (748-798) n = 2	-	624 (119-1429) n = 6
Lydonia Canyon	233 n = 1	130 (67-164) n = 2	-	145 (67-322) n = 3

of the central shaft by tilefish swimming movements. Secondary burrows that interconnect to the main burrow make the upper portion of some tilefish burrows "honey combed" and prone to eventual collapse. Additionally, we observed clay clumps near occupied burrows that suggested to us that oral excavation by tilefish was an important means of burrow construction. These mechanisms explain the formation of conical shaped burrows, but do not account for the larger diameter (estimated up to 9-10 m across) crater-like features that we observed. These U-shaped features were secondarily eroded like funnel-shaped burrows, and had as many as three individual burrow shafts dug into their lower portions. Craters probably formed by the coalescence of closely spaced vertical burrows that widened and deepened.

Some burrows may be very old, if they are occupied by successive generations of tilefish (individuals live in excess of 30 yrs, Turner et al. 1983, and the clay into which they are dug is Pleistocene). However, a recent experiment suggested that if a burrow were unoccupied it would fill with sediment in maximum time of one year. We removed the fish from a large burrow (2 m diameter), marked the burrow location with an acoustic transponder. When we returned one year later the burrow was almost completely silted in and unoccupied.

Species that are sparse over open bottom are concentrated in and around burrows, forming a definite "tilefish community" (Table 2). Approximately 60-80% of all galatheid crabs, cancrid crabs and blackbellied rosefish counted in photographs were associated with burrows. At times of peak activity as many as 2 galatheids, 5 goneplacids, 5 Anthias sp., 1 Urophycis sp. and 1 Helicolenus dactylopterus were photographed at a single large (2 m diameter) burrow.

Time-lapse photography revealed distinct activity patterns for some associated species listed in Table 2 (Fig. 3). Galatheid crabs were more frequently photographed during the day, as were Anthias

nicholsi. H. dactylopterus may be crepuscular because they were most frequently photographed during early morning and late afternoon. Urophycis sp. activity showed no particular periodicity. Goneplacid crabs were clearly nocturnal, never appearing in photographs exposed after 0810 hr and before 1910 hr.

Small crabs and fishes probably concentrate around burrows for several reasons. They all appear to be shelter seeking and the complex topography of the burrow provides that. The goneplacid and galatheid crabs are also burrowers and the exposed clay in burrows may be the best malleable substrate available. Also, the swimming actions of tilefish probably keep their small secondary burrows at least partially free of fine silt. Finally, if tilefish feeding and excretion make the burrow a more resource rich environment, then associated species may gain trophic rewards. Whatever the exact nature of the benefits of burrows, the advantages gained must exceed the disadvantages of danger from predation, because some associates (in particular galatheid crabs, cancrid crabs and probably Helicolenus dactylopterus) are components of the diet of tilefish (Turner and Freeman in prep.).

As in the case of Pueblo habitats, tilefish seemed to orient to a particular burrow, especially around Hudson Canyon. In numerous instances when rotenone was injected into burrows fish exited but remained nearby, and in some instances attempted to re-enter the burrow. These fish had not been incapacitated by the rotenone as they quickly swam away when touched by the submersible manipulator arm.

Most direct in situ observations have indicated single occupancy of burrows. However, time-lapse photographs showed a male and female (sexes distinguished by larger adipose crest in males) utilizing the same burrow and displaying definite temporal activity patterns (Fig. 3). The female was seen repeatedly in photographs

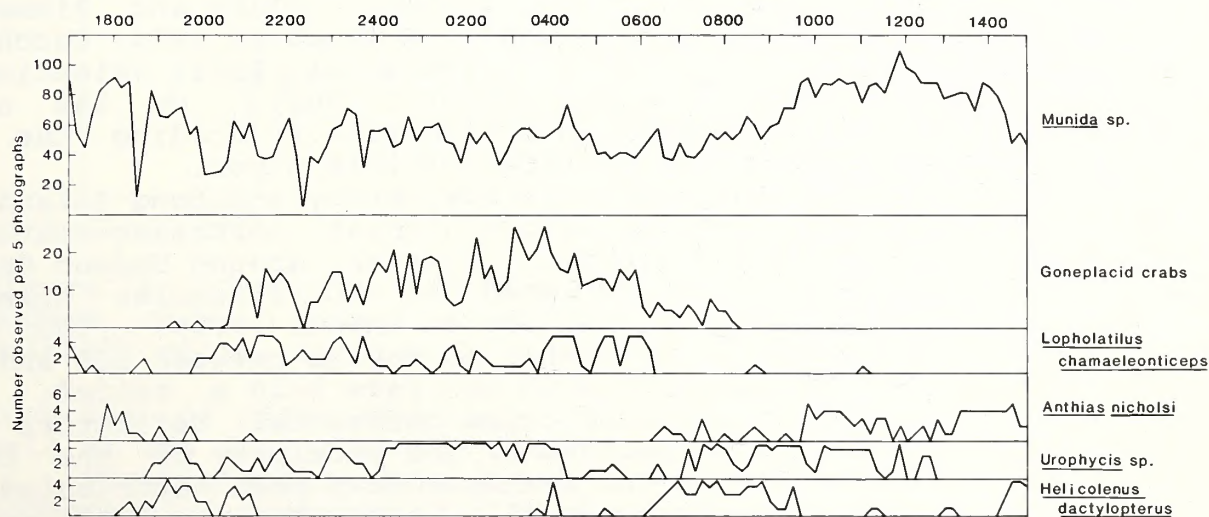


Figure 3. Temporal activity of tilefish and several associated species at a vertical burrow in Hudson Canyon, determined from time lapse photographs (from Grimes et al. 1986).

from about 1630 to 2230 hr. mostly entering and/or exiting the burrow, and seldom hovering above or around the burrow. At about 2230 hr the male appeared and was observed until 0700 hr, usually above the burrow margin or central shaft. We do not know if the female was in the burrow. However, because the male was not seen entering or exiting the burrow may suggest this was so. From 0700 hr until 1500 hr the female was observed near the burrow in very few photographs taken between 0900-1000 hr and 1100-1200 hr. This may suggest that for the most part both sexes were away from the burrow foraging during the day.

The non-corresponding temporal activity patterns of tilefish and some associated species (galatheid crabs, A. nicholsi, Urophycis sp. and H. dactylopterus) and the knowledge that these species are prey of tilefish (Turner and Freeman in prep.) suggested that predation was a powerful organizing force in communities associated with burrows, and probably Pueblo habitats as well. The burrow and Pueblo village associated communities are complex ecological systems featuring physical and biological interactions with tilefish acting as a keystone (Paine 1966) species. They shape the habitat and provide a physically suitable environment (perhaps trophically advantageous as well) for other members of the community. They interact with galatheid and goneplacid crabs to further structure and develop the habitat. Finally, they enjoy a symbiosis (probably mutualistic) with at least galatheid crabs, and through predation probably influence community structure. Clearly, the exact nature of the relationships between tilefish and associated species (i.e. trophodynamics and the possibility of an unusually efficient flux of nutrients through the community) are fertile areas for future research.

Sea Floor Processes

Bioerosion is increasingly recognized as an important process generating sediment and shaping bottom topography along the continental margin (Warne and Marshall 1969; Dillon and Zimmerman 1970; Stanley 1971; Warne et al. 1971; Rowe et al. 1974; Cacchione et al. 1978; Ryan et al. 1978; Warne et al. 1978; Valentine et al. 1980; Malahoff et al. 1981; Hecker 1982). On the outer continental shelf tilefish play an active role in eroding the sea floor as described in previous sections of this paper.

The outer continental shelf off New Jersey and Long Island is mostly shaped by an evenly spaced linear northeast-southwest trending ridge and swale topography. However, around Hudson Canyon this regular topography is replaced by an irregular hummocky topography (Fig. 4; Ewing et al. 1963; Knebel 1979). The area covers about 800 km and occurs mostly at depths between 120 and 500 m. Hummocks are irregularly spaced and have 1-10 m relief. The hummocks are clearly erosional because horizontal reflectors are truncated at the flanks. Because of the proximity of the rough topography to Hudson Canyon the features have been attributed to canyon related processes (Ewing et al. 1963; Knebel 1979). Our knowledge of tilefish, habitat, ecology and behavior has led us to hypothesize that bioerosion by tilefish may be the cause of the rough bottom topography (Twichell et al. 1985).

There is a close correspondence between the fishing grounds for tilefish and the extent of the rough topography: Fig. 4 outlines the

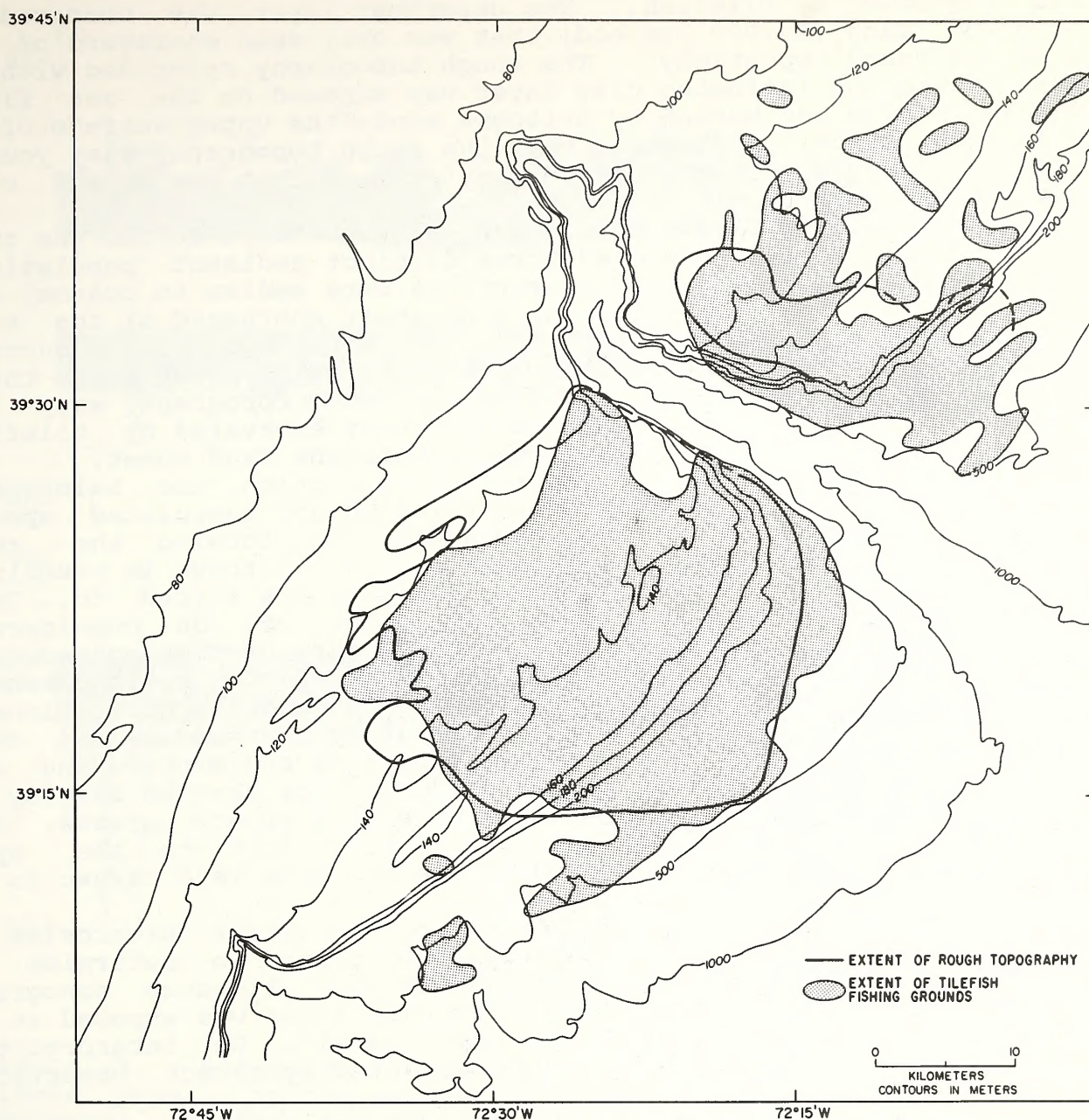


Figure 4. Comparison of the extent of the rough topography around Hudson Canyon with the extent of the tile fish grounds (from Twichell et al. in press).

location of 1634 individual longline sets made from 1978-1982, as well as the extent of the rough topography.

Stratigraphic data supported our contention that the hummocky topographic features were Holocene rather than Pleistocene in age. Seismic profiling showed three distinct layers. The oldest layer, an acoustically massive layer that was exposed north of Hudson Canyon, consisted of medium to coarse sand. Overlying the massive layer was a well laminated layer that observations from a submersible showed to be stiff grey clay, and it was this layer that

was burrowed by tilefish. The uppermost layer was composed of Holocene sand (13,000 yrs old) that was only seen shoreward of the area of rough topography. The rough topography coincided with the area where the laminated clay layer was exposed on the sea floor. Where the clay was buried by Holocene sand, the upper surface of the clay was smooth, indicating that the rough topography was younger than 13,000 yrs, otherwise the clay surface that was buried would also be rough (Twichell et al. 1985).

Grain size analysis of sediment samples taken across the three stratigraphic layers indicated three distinct sediment populations. The largest and smallest size fractions were medium to coarse sand that characterized the Holocene sand sheet shoreward of the rough topography, and silty-clay that characterized the burrowed substrate. The third sediment type was a thin veneer (less than 1 m) of sediment that covered much of the rough topography away from burrows; it was a mixture of the silt-clay excavated by tilefish, and sand transported offshore from the Holocene sand sheet.

The basic process of burrow construction and maintenance through the combined activities of tilefish and associated species over time may provide the mechanism for forming the rough topography. Considerable maintenance of the burrows is required; the vacant burrow we revisited after one year was silted in. Thus, sedimentation was considerable, and a fish must do considerable work to maintain a burrow. Such a rapid rate of filling suggests that juveniles probably do not occupy large existing burrows because they could not maintain them. Therefore, successive generations of tilefish would mostly dig new burrows rather than occupy old ones. Also, we frequently observed clouds of fine sediment coming from burrows, and once suspended it was evidently transported away by the current because there were not sediment mounds around burrows. Much of the suspended sediment may have been lost to the upper continental slope because mean drift in the area is 8 cm/sec to the south.

Having identified a mechanism for sea floor bioerosion we evaluated its extent by using sidescan sonar to determine the spatial distribution of tilefish burrows. Sidescan sonographs showed burrows only in areas where the clay layer was exposed at the surface of the substrate (Fig. 5 - upper panel). Our interpretation of burrows seen on sonographs was validated by direct observation during submersible dives.

We also used sidescan sonar to estimate mean burrow density ($2500/\text{km}^2$), and combined that information with the calculated sediment volume in a 2 m diameter burrow (1.3 m assuming a perfect conical shape 1.5 m deep) to estimate the amount of sediment removed from the 800 km² area; that amount was 2.6 million m³. Since each generation of fish mostly dig their own burrows, rather than occupy existing ones, the amount of sediment removed would be much more than the amount removed to form the present burrows.

Thus, tilefish effectively remove large sediment volumes. However, how can burrowing form large scale hummocky topography given that individual burrows and the rough topography were of very different scales? We believe that the larger scale hummocky topography is a consequence of spatially differential erosion rates over a long time period. Our analysis of the spatial distribution of burrows, i.e., frequency distribution of the distances between

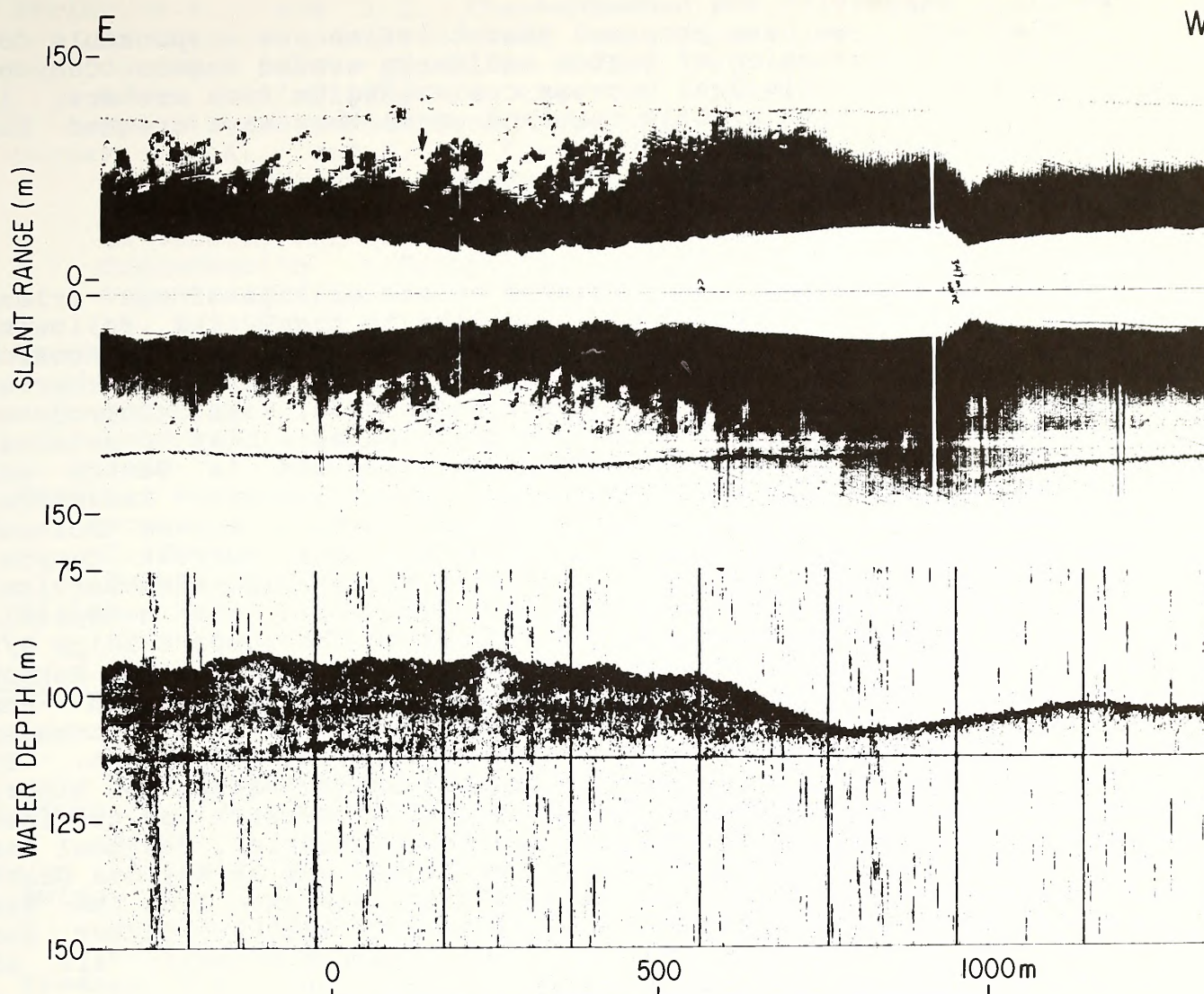


Figure 5. Sidescan sonograph (upper panel) and 3.5 kHz profile (lower panel) on the eastern side of the Hudson Canyon. On the sonograph, tilefish burrows are evident as points of strong acoustic reflectance with a shadow in front of them. The 3.5 kHz profile shows the rough topography and laminated clay substrate on the left portion of the record, its erosional truncation, and the exposure of the underlying sand on the right part of the record. Note the disappearance of tilefish burrows at the boundary of the clay substrate (from Twichell et al. 1985).

adjacent burrows (taken from sidescan sonographs and from direct measurements along submersible transects), showed that burrows were contagiously distributed (Twichell et al. 1985). In areas where burrows were clustered, bioerosion should be more rapid than where burrows were scarce. Furthermore, the dimensions of burrow clusters (up to 200 m across) were similar to the size of the larger

depressions separating the hummocks.

In summary, we have proposed that tilefish are responsible for the extensive bioerosion of bottom sediments around Hudson Canyon. By burrowing (and individual burrows coalescing to form craters) in clusters for the past 8 to 10 thousand years they have created the large scale hummocky topography.

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OBSERVATIONS OF GELATINOUS ZOOPLANKTON AND MEASUREMENTS OF VERTICAL BIOLUMINESCENCE IN THE GULF OF MAINE AND ON GEORGES BANK

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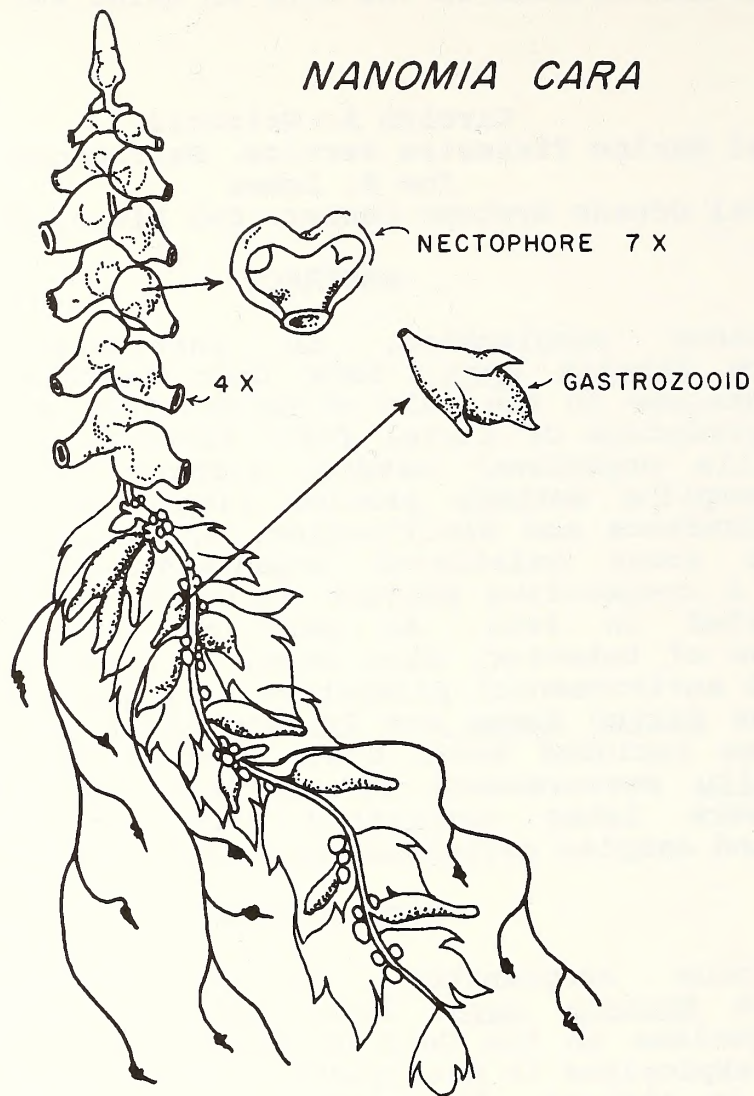
ABSTRACT

Gelatinous zooplankton, in particular the physonect siphonophore Nanomia cara, have been implicated as gill net fouling organisms in the Gulf of Maine. They are also considered potential predators of larval fish. However, little is known of these fragile organisms' natural history and behavior because standard sampling methods provide little more than indices of relative abundance and distribution. In response to the need to learn more about gelatinous organisms and their impact on fisheries, a cooperative project entitled "Water Column Ecology" was initiated in 1982. As part of this program in situ observations of behavior, size density, distribution, associated species and environmental parameters were made using the research submersibles Nekton Gamma and Johnson Sea-Link. This cooperative project also included Naval Ocean Systems Center personnel who made in situ measurements of vertical bioluminescence. These profiles were later correlated with the observed plankton community and samples collected throughout the water column.

INTRODUCTION

Gelatinous zooplankton, in particular the physonect siphonophore Nanomia cara, have been implicated as gill net fouling organisms in the Gulf of Maine. They have undergone two population explosions in past years - one in the winter of 1975-76 and again in 1981-82. During those periods they reduced gill net fishing efficiency by as much as 90%, which resulted in substantial economic losses to fishermen of northern New England.

Siphonophores, an order of Coelenterata, are divided into three suborders: The Calycophorae (Lenchart, 1854) which have no nectophores and no float, the Cystonectae (Haechel, 1888) which have a large float and no nectophores such as Physalia, the Portuguese Man O'War, and the Physonectae (Haechel, 1888) which have nectophores and a small float; Nanomia cara (Figure 1) belongs to the latter (Totten, 1965). Agassiz (1865) first described N. cara, including the juvenile stages, from specimens he collected in Massachusetts Bay. Little about this organism's biology has been added to the information Agassiz provided over one hundred years ago. Bigelow (1925) states that N. cara is the only siphonophore which is a regular inhabitant of the Gulf of Maine. While it is common in the Gulf of Maine, he did not find it along the south or west coasts of Cape Cod and only rarely on Georges Bank during his two year sampling period.



SCALE:

— 10 mm = 2.5 mm, or 4 X

— ENLARGED STRUCTURES
10.5 mm = 1.5 mm, or 7 X

Figure 1. *Nanomia cara* is a physonect siphonophore endemic to the Gulf of Maine.

Very little is known about this particular organism; however, recent information (Purcell 1981a, b) has shown that many siphonophores are either occasional or common predators on fish larvae. Lough (1976) and Larson (Peter Larson, Bigelow Laboratory, W. Boothbay Harbor, ME, personal communication) noted an inverse relationship between siphonophores and fall spawned herring larvae in the Georges Bank/Gulf of Maine areas during the periods of the two recent "blooms".

Because of the fishery implications of this organism, a program was established in late 1975 in an attempt to learn more of its natural history, if only to be able to predict years or areas of bloom conditions as an aid to local fishermen.

METHODS AND RESULTS

Plankton Survey

The first approach was to look at zooplankton samples taken in the Gulf of Maine and on Georges Bank during the fall and winter of 1975 and spring of 1976. These samples were collected as part of the Northeast Fisheries Center's (NEFC) MARMAP (Marine Resources Monitoring, Assessment, and Prediction) program. We used 61 cm paired bongo nets (0.505 and 0.333 mm) and did double oblique tows from the surface to 2 m above the bottom or to a maximum of 200 m.

These recent surveys of siphonophore distribution and abundance bear out several of Bigelow's (1924) suppositions. One is that they are most abundant in fall and winter (Rogers - Griswold nee Rogers, 1978) with decreasing abundance in spring (Rogers, 1979). Based on these studies and reports from local fishermen in years of high abundance, one center of population density appears to be the western Gulf of Maine, probably representing a resident population.

MARMAP survey samples have also yielded siphonophores, presumably N. cara, in the Northeast Channel around the Scotian Shelf and into the Bay of Fundy. Generally this population is of smaller size and appears discontinuous with the more western population. Sameoto (1982) found N. cara was the predominant siphonophore in shelf waters off southeastern Nova Scotia. However, it was not found in slope waters of the same area. It is likely therefore that some N. cara enter the Gulf of Maine through the Northeast Channel in the upper 75 m which is Scotian Shelf water. Some of the population extends around the southern coast of Nova Scotia, up into the Bay of Fundy and along the eastern coast of Maine. Redfield (1936) followed a population of Limacina retroversa as it entered through the Northeast Channel area. The distribution of recent immigrants is somewhat similar to what we found for N. cara (Rogers, 1979).

Bigelow (1926) noted that N. cara is rarely found on Georges Bank. Our study (Rogers, 1978) corroborates this, although some are found in the Great South Channel area. On a recent cruise (Knorr 94, June 1982), SCUBA divers including myself, made a dive at the edge of the shelf off southern New England (40°10.04'N, 70°59.97'W). Siphonophores were extremely abundant in the upper 30 m (10°C). The predominant species was Agalma elegans, but N. cara was also present. This indicates that N. cara's southern

distribution may be restricted to shelf/slope water fronts rather than more coastal waters south of Cape Cod. This organism is also common off the U.K. (Fraser, 1967).

Continuous Plankton Recorders

Monthly continuous plankton recorder (CPR) data for 1981 in the Gulf of Maine from Boston, MA to near Cape Sable, NS indicated that a swarm of siphonophores began in the central Gulf of Maine in late June-July and spread across the Gulf from Cape Ann to Cape Sable by September when estimates of abundance were highest. The population either decreased or, more likely, was below the 10 m CPR depth in November. An alternate explanation was that the population sampled on the Scotian Shelf came from the east (Daniel Smith, Atlantic Environmental Group, Narragansett, RI). We have continued to examine the MARMAP samples and CPR records for siphonophores; in addition, we initiated two short cruises in fall 1982 and 1983 to conduct a special survey because of a second bloom in the 1981-82 winter-spring period.

Ongoing MARMAP plankton surveys, special surveys and CPR records can indicate presence or absence of these organisms. However, these types of sampling programs provide only relative information on areal distribution and seasonal abundance because of the patchy horizontal and vertical distribution of N. cara populations, which are often at depths greater than is routinely sampled, and the fact that parts of the organism most easily recognized are readily fragmented and may not be sampled.

SCUBA

SCUBA can be used successfully for collections and observations of many fragile gelatinous organisms (Hamner et al., 1975; Harbison and Madin, 1979). However, its use is not practical in the cold, deeper waters of the Gulf of Maine on a regular basis.

Manned Submersible Studies

Gelatinous Zooplankton

In past studies, gelatinous zooplankton abundance, size and distribution have been adequately estimated through the use of manned submersibles (Barham, 1963, 1966). Therefore, in June 1976 following intensive MARMAP surveillance of the area (Rogers, 1979), we conducted a number of submersible (Nekton Gamma) dives in Wilkinson Basin (Western Gulf of Maine) to estimate the abundance and density of N. cara and establish its daytime depth distribution (Rogers et al, 1978). We found siphonophores only at stations where the water depth was >72 m and only below the thermocline in a temperature range of 5.5-7.5°C. Generally, larger colonies were found at greater depths than the smaller ones. Density ranged from <0.1 to 8/m³. No salinities were taken at the time so a profile of salinity preference and possible water mass origin was not possible. These preliminary dives and the subsequent (1981-82) "bloom" of these organisms indicated that more needs to be known concerning the life history and distribution of this important animal.

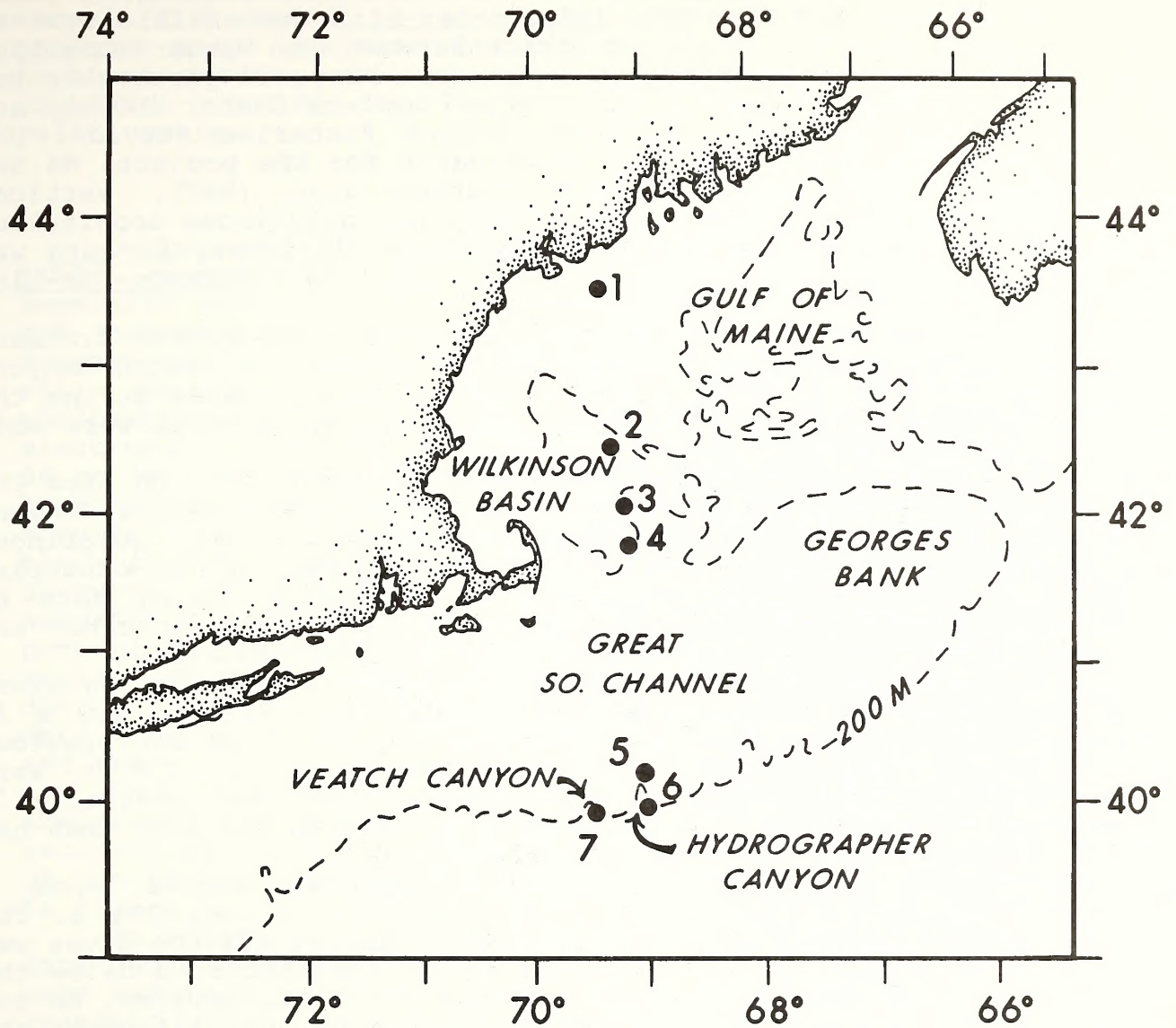


Figure 2. Location of dive sites for the 1983 Johnson-Sea-Link Water Column Ecology cruise.

In the fall of 1982 we developed a submersible proposal entitled "Water Column Ecology". It was new type of proposal from the NEFC in that it focused on water column communities and environmental parameters rather than on the benthos. The proposal was funded jointly by NOAA and the Harbor Branch Foundation (HBF) which owns and operates the Johnson-Sea-Link submersible system. The project was a cooperative effort between Dr. Marsh Youngbluth of the Harbor Branch Foundation; the U.S. Navy, in particular Dr. Jon Losee and David Lapota, Naval Ocean Systems Center (NOSC); and Carolyn Griswold, NEFC, National Marine Fisheries Service. Dr. Kurt Stehling, NOAA, acted as coordinator for the project. We had three main areas of interest: marine snow (HBF), vertical distribution of bioluminescence (NOSC), and gelatinous zooplankton (NEFC). Because of its possible impact on fisheries, N. cara was designated the target species for the 1983 Johnson-Sea-Link mission.

We occupied 7 stations, 4 along a permanent MARMAP transect in the Gulf of Maine and three in Hydrographer and Veatch Canyons (Figure 2) from July 10-17, 1983. All dives were made during the dark between 2000 and 0500 hours. Three two-hour dives were made each night.

A series of seven dives were made at depths ranging from 200 m in the Gulf of Maine to 600 m in Veatch and Hydrographer Canyons during which observations and collections of gelatinous zooplankton were made as well as observations of co-occurring species. Vertical bioluminescence was measured during each of these dives. Methods and combined results of bioluminescence and species distribution observations will be described below.

N. cara was observed at each station although not on every dive. Individual colonies ranged in size from 0.2 to 2.0 m in length. This size range is considerably smaller than our previous submersible observations where individuals up to 3.7 m were observed. Maximum density on one dive was $3/\text{m}^3$, but generally it was orders of magnitude less during this mission and less than had been reported earlier (Rogers et al., 1978).

Vertical distributions of siphonophores varied from a relatively narrow band of 91 m on one dive to over 274 m. The total vertical range for animals observed during all the dives was 27 m below the surface to 568 m. Most colonies occurred below the thermocline at temperatures of approximately 6°C , however, on one dive siphonophores were observed at 13.0°C . Although the organisms were widely distributed vertically, it was difficult to ascertain whether or not this was a result of diel migrations or a normal distribution pattern. Our failure to verify whether or not migrations were occurring lies in the fact that the animals were so sparsely distributed that directed movement could not be determined.

A total of 26 siphonophores were captured alive and intact from the submersible, an impossible task using conventional net gear. Each was preserved and later analysis of stomach contents showed that dominant food items were copepods (Calanus finmarchicus, Acartia sp., and Metridia lucens) followed by euphausiids (Meganyctiphanes norvegica and Thysanoessa spp.) and amphipods (Parathemisto sp.). One arrow worm (Sagitta sp.) and one house fly (Diptera sp.) also had been ingested.

Visual observations and identification of potential zooplankton prey species from the submersible sphere correlated well with that which was ingested by the siphonophores. Both the size range and type of prey support the supposition that N. cara is an opportunistic feeder and an omnivore, so the hypothesis that larval fish would be a likely prey in areas or times when predator-prey densities are high seems a reasonable assumption. On-board feeding studies using larval fish are planned for the immediate future to verify the possibility of such a relationship.

Vertical Bioluminescence

During each dive vertical bioluminescence was measured and later correlated with recorded observations of zooplankton community structure. Bioluminescence was measured using both open and pumped detectors mounted on the outside of the submersible forward of the sphere. Only the pumped or closed system detector will be discussed here. The detector consists of a photomultiplier tube (PMT) (RCA 857A) and the associated electronics fitted in a Benthos pressure housing (12.7 cm O.D. x 56 cm length) which is pressure tested to 7000 m of seawater. The housing is fitted with a 3 cm thick ultraviolet transmitting acrylic pressure window. The intake is an S-band of 7.5 cm I.D. black plastic pipe used as a light baffle which is mounted facing downward. A turbulent volume of seawater is obtained by pulling seawater through the PMT "viewing" chamber (60 ml volume) by a pump at a constant flow rate of 1 liter/sec. The PMT is used in photon counting mode, and the PMT pulses are recorded in the diving compartment of the submersible in two ways: average count data (counts/60 sec) are obtained by use of an Ortec 874 scaler, and every 60 sec, 10 sec scans of the PMT data are obtained with 10 msec resolution, using two Davidson 1024 multichannel analyzers. The scaler and analyzer are controlled and their data recorded by an Otrona Attache microcomputer (Figure 3). Examples of the 10 msec data and the average count data vs. depth are shown in Figure 4.

In addition to in situ measurements, organisms including N. cara were collected throughout the water column. The organisms were returned to shipboard, isolated and placed in 5 ml vials in running filtered seawater. They were held in the dark for 24 hours then placed in a laboratory detector, which consists of two PMT's which view the vial. Each organism is stimulated to flash when the water is drawn off by means of a vacuum pump leaving the organism dry on filter paper in the vial. After the flash is recorded the organism is removed and preserved for later identification. An example of flash response from N. cara can be seen in Figure 5. Since each organism type has a typical signature, these signatures will be used eventually to characterize community structure from in situ measurements such as those seen in Figure 5.



Schematic Of Bioluminescence Sensors On The JSL Submersible

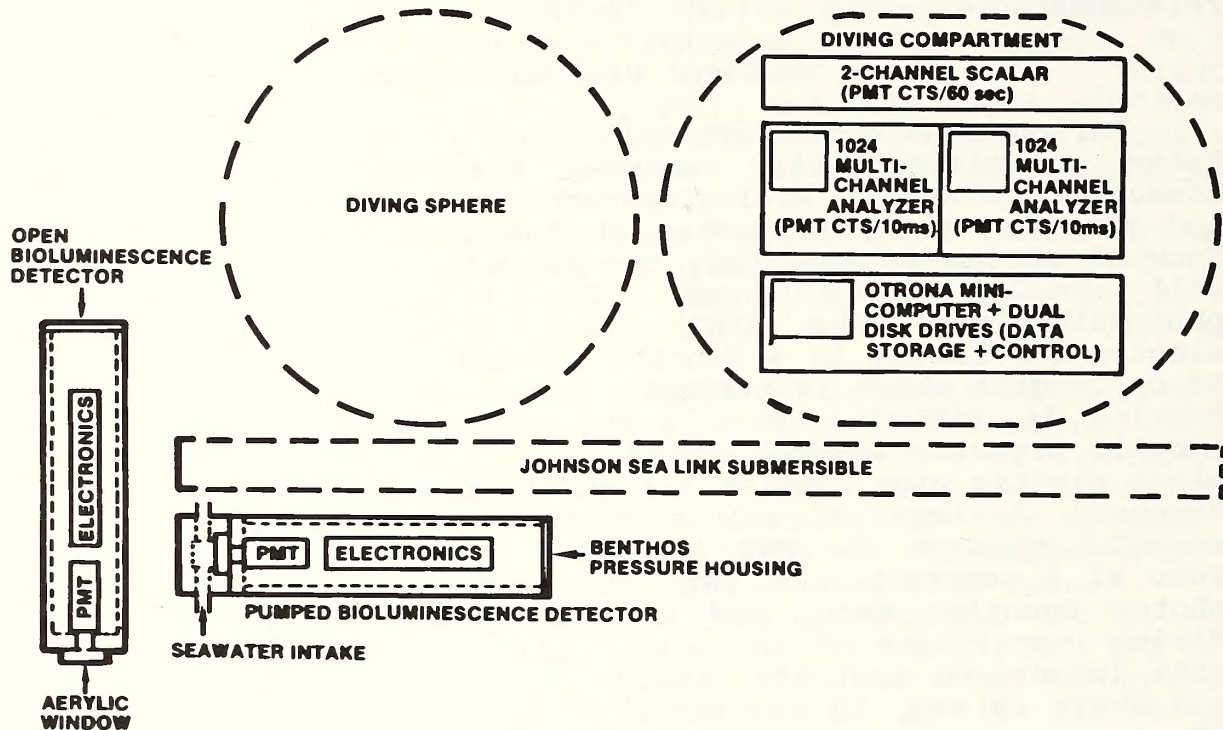


Figure 3. Schematic of the bioluminescence sensors for the Johnson-Sea-Link. Only the pumped detector results are discussed.

DISCUSSION

When observations of vertical zooplankton community structure and bioluminescence are combined little correlation can be seen (Figures 6, 7). Bioluminescence is highest in the upper 100 m with a maximum usually occurring right below the thermocline. This area corresponds to the chlorophyll maxima layer where biomass and productivity are high. Results from organisms collected from areas of high bioluminescent activity and tested in the onboard system bear out the conclusion that the upper layers

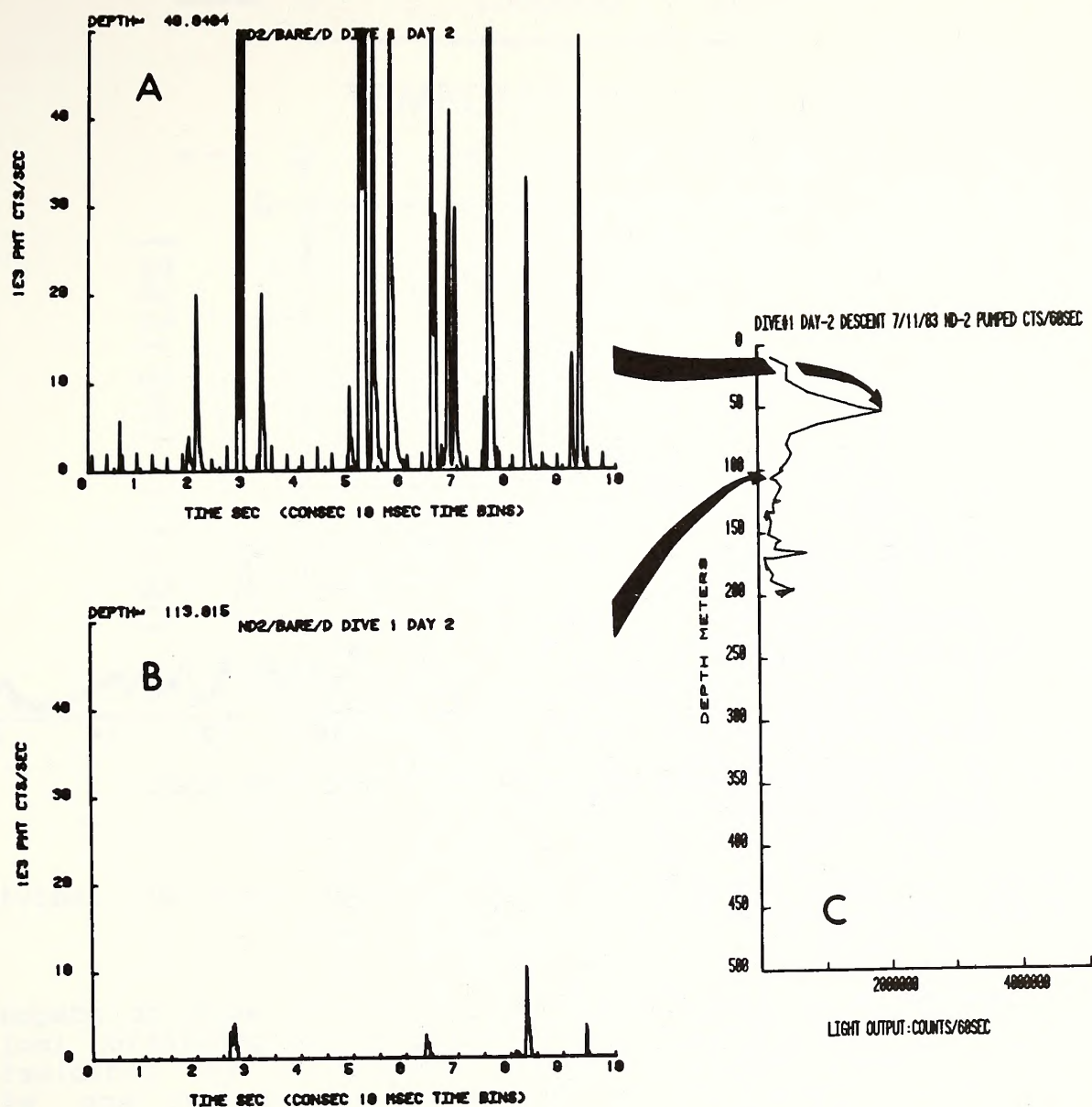


Figure 4. The vertical bioluminescence profile (C) from Station 2 with two 10 msec time bin individual flash records from depths of: (A) 50 m, and (B) 114 m.

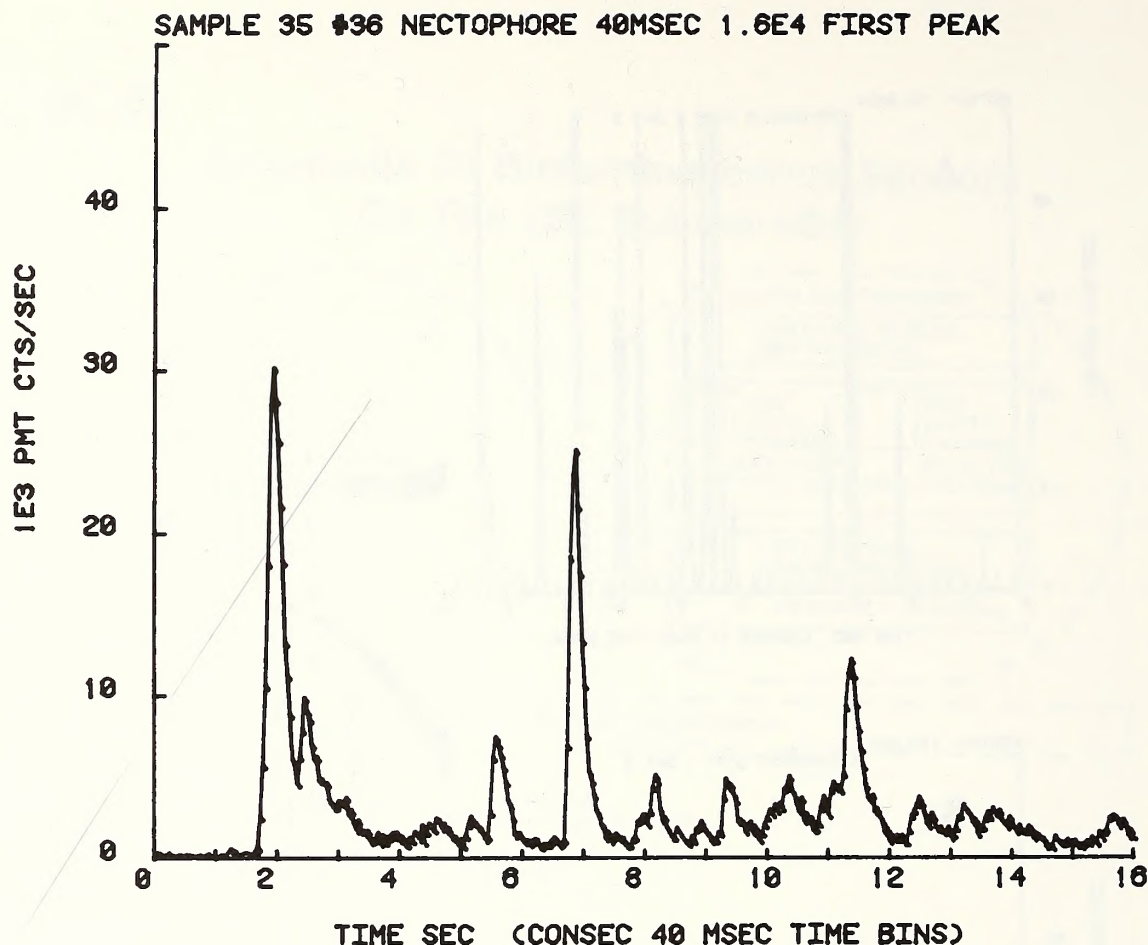


Figure 5. The bioluminescent "signature" from an individual Nanomia cara nectophore.

are dominated by small organisms not easily seen or adequately identified by an observer. The bioluminescing population includes dinoflagellates, copepods, larval euphausiids and radiolarians. The larger more easily recognized organisms are widely distributed, but usually occur below the thermocline. Many of these are luminescent such as siphonophores, ctenophores, euphausiids, some fish, squid and so on, but the bioluminescent depth curve does not reflect this, indicating that these organisms are not uniformly distributed. By combining both types of observations a somewhat more complete view of the water column community emerges; however, even that is biased by attraction to or avoidance by organisms of the white lights of the submersible. The picture is further complicated by the fact that when the submersible lights are off large strings and other configurations of bioluminescence can be seen. They are difficult to identify and when the lights are turned on nothing recognizable can be detected.

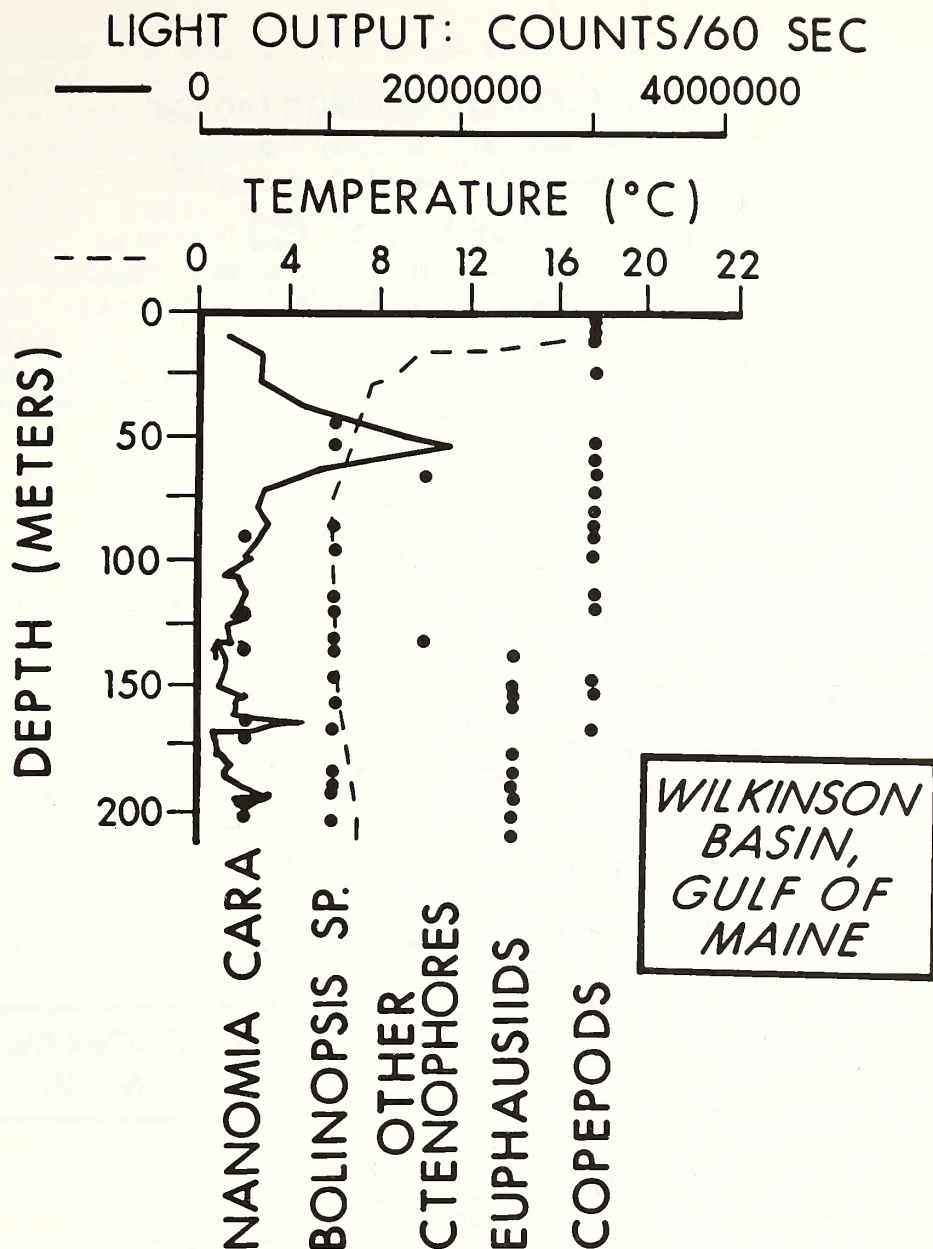


Figure 6. The measured vertical bioluminescent profile and observed zooplankton community from Station 2. Dark circles represent observed presence of organisms only.

In order to try to further identify such organisms, we are proposing to use red, black or ultraviolet (uv) lights mounted on the submersible. Patterns of fluorescence which would show up under the ultraviolet lights could be video taped and possible identifications made using image analyzer techniques.

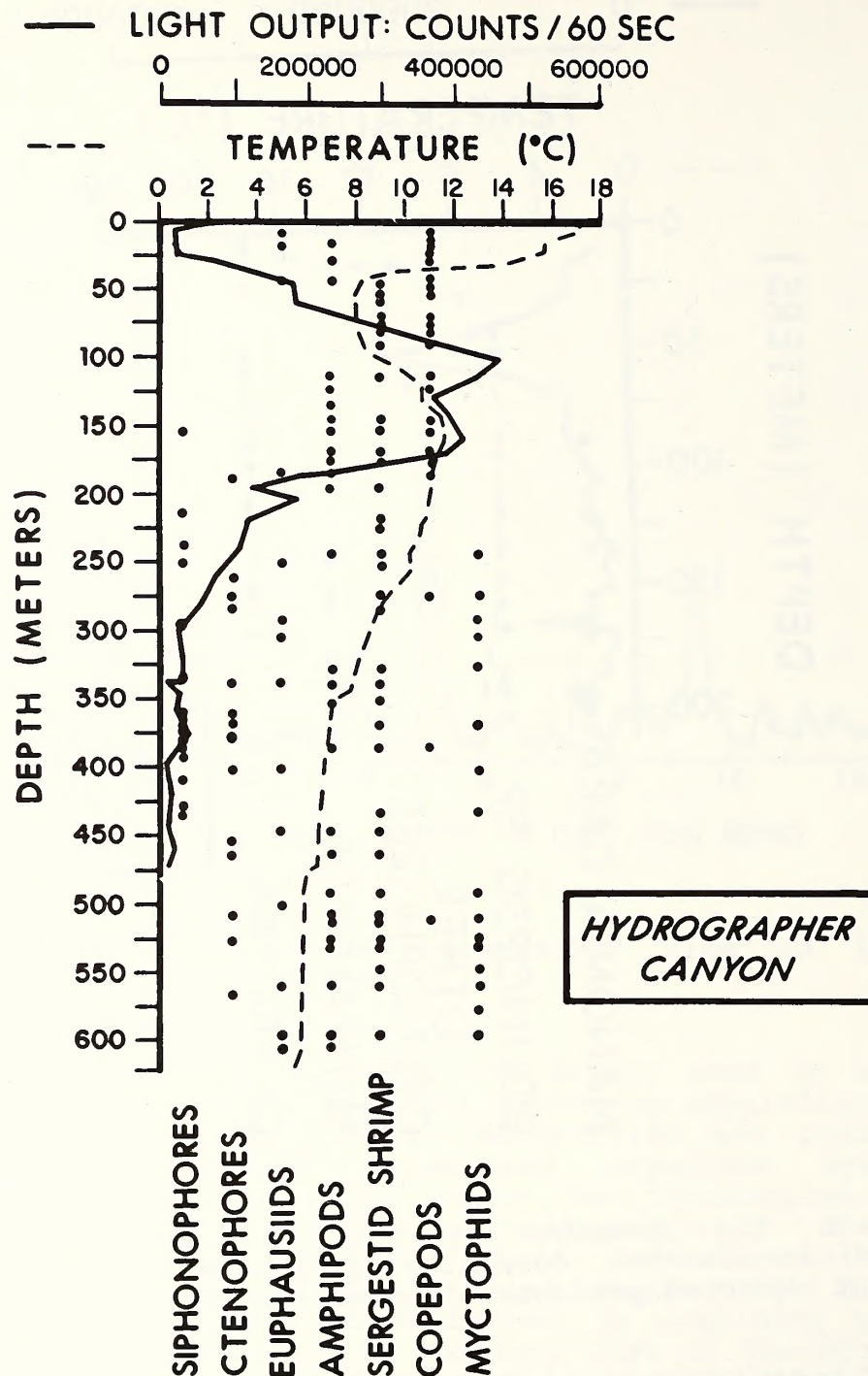


Figure 7. The measured vertical bioluminescence from Station 6. Bioluminescent activity does not correlate well with the observed zooplankton community.

CONCLUSIONS

In order to solve problems regarding the natural history of fragile gelatinous organisms such as Nanomia cara, no one method of observation and collection is sufficient. Standard plankton surveys provide information on relative seasonal abundance and distribution. Continuous plankton recorder information can add to that and give indication of centers of population activity and to some extent origins of the populations. Information from these sources together with published distributional data establishes local population centers and areas of immigration. SCUBA also can be employed to establish distributional patterns and is useful in making in situ observations and collections. However, this method is of limited value in the deep waters of the Gulf of Maine.

Use of submersibles has provided us with the best specific information on size, vertical distribution, density, swimming speed, and co-occurring species. Collections of living, intact organisms verified identification and allowed for onboard experimentation and analyses of stomach contents. Such collections indicate that N. cara has bioluminescent properties and that it is a non-specific or opportunistic feeder, possibly a predator of larval fish.

Comparisons of observed organisms and bioluminescence throughout the water column indicates that small organisms not identifiable to an observer are responsible for most of the measured bioluminescence and these organisms are most abundant in the upper 100 m with a maximum around the thermocline which also represents the area of the productive chlorophyll maxima layer. Large luminous organisms which can be identified by the observer are not being sampled by the pump system, probably because of their ability to avoid gear and because they are less numerous than the small organisms.

New techniques are proposed for characterizing bioluminescent forms not sampled or observed using normal methods.

ACKNOWLEDGEMENT

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DIRECT OBSERVATION IN PLANKTON ECOLOGY

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ABSTRACT

Until recently, most plankton ecologists have relied on blind sampling, mainly with towed nets, to study distribution patterns, to collect organisms for experiments, and to infer behavior and trophic relationships. As a result, plankton ecology has lagged far behind terrestrial and nearshore benthic ecology. With the development of in situ techniques, it is possible to observe the behavior of planktonic organisms directly, to collect them in good condition for experiments, and to study distribution patterns at scales as small as a centimeter. Most of this work has been with SCUBA, so that only a minute fraction of the organisms in the open sea has been studied. Limited work with submersibles has demonstrated that there is an abundant, as yet undescribed, mesopelagic fauna, with complex and interesting interrelationships. To develop an understanding of the open ocean as an environment, it is essential that we observe planktonic animals directly, and study behavior in situ, as well as in the laboratory. At present, observations and collections with submersibles are the methods of choice, but future plans should include an undersea research vessel capable of spending long periods of time at depth.

Although most people consider the great age of biological exploration as essentially over, to those of us working on planktonic animals it has just begun. Three-quarters of the Earth is covered by water, at an average depth of more than two miles. All of this volume is a suitable habitat for life, so that the deep oceans provide more than two hundred times more space for animals to live than the space on all the land masses put together (Childress, 1983). This means that most of the Earth's creatures live in an environment so different from the one we experience that we can only dimly imagine what life there might be like. Sunlight penetrates to only a few hundred meters and seasonal changes do not penetrate very deeply, so that most of the animals in the sea live in a world of total darkness and constant temperature. There are no physical boundaries between the surface and the bottom; all of the surfaces in the deep ocean are produced by the organisms themselves. Since the animals living in the water column are moving with the currents, the midwater world appears motionless and free from turbulence. Over the period that life has existed on Earth, the land masses have changed and moved, but the ocean basins have always been in continuous connection with one another. Thus the deep sea has remained the same, at least in a physical sense, for as long as it has existed, although the organisms inhabiting it may have changed. I say "may have changed", since there are very few fossil remains of

open ocean plankton, and thus we cannot know what the organisms inhabiting the deep sea in Precambrian times were like. We can be fairly certain, however, that the physical structure of the deep ocean was much the same then as today. This largest, most constant, and most alien (to us) of all the different environments on Earth is also the most poorly understood.

It is difficult for a scientist to talk about the things he does not know, and how necessary it is that we continue to explore, since science is expressed in terms of what is known. This leads to the general impression that a great deal is known. But a comparison of the kinds of things we know about animals living in the open sea with the kinds of things we know about animals living on land reveals the ignorance of those of us in plankton biology. We know virtually nothing about the way midwater organisms live -- how they capture prey, avoid predators, find mates, how long they live, whether they have courtship rituals or other social interactions, and all the other sorts of information that makes terrestrial biology so interesting. We need to try to learn these details about the lives of midwater organisms simply because the deep ocean is so different from the environments that we are familiar with that it is the best comparative system we have until life is discovered on another planet. A better understanding of how animals live in midwater cannot help but teach us more about how animals live in general, and how they interact with their environment. For example, we take it for granted that animals should be opaque, with strong skeletal supports, but many of the organisms living in midwater are transparent, with gelatinous bodies and long tentacles. This leads us to see that terrestrial animals are constructed the way they are to deal with intense solar radiation and the effects of gravity on bodies unsupported by water, two physical constraints that are missing in the deep sea. Yet some plankton ecologists have proposed the very opposite, saying that midwater animals are transparent to avoid predators, and flimsily-constructed because food is so scarce (see Marshall, 1971). How then to explain "extraneous" pigment spots on otherwise transparent animals (Figs. 1 and 2)? How then can we explain the fact that diaphanous jellies are parasitized by much more substantial crustaceans (Madin and Harbison, 1977; Harbison et al., 1977)? A recognition of past misconceptions points up the fact that we need to free our thinking from its land-based biases, and enter the deep ocean environment and look around.

I have been working on a heterogeneous group of animals -- gelatinous zooplankton -- for the past fifteen years. Most of my work has been with SCUBA, in the upper 30 meters of the open sea. In 1975, I had my first dive in a submersible, the DSRV ALVIN (Woods Hole Oceanographic Institution), to look at animals in midwater. Since then, I have used the ALVIN on other occasions, the DSRV JOHNSON-SEA-LINK (Harbor Branch Oceanographic Institution) and the WASP diving suit (Oceaneering) for a total of over 1000 hours observing gelatinous animals in their natural environment.

Gelatinous plankton comprise a large, generally unrelated group of organisms whose body tissues are mostly water. This group includes colonial radiolarians, jellyfish, siphonophores, ctenophores, pteropods, salps, doliolids, and even some fish and

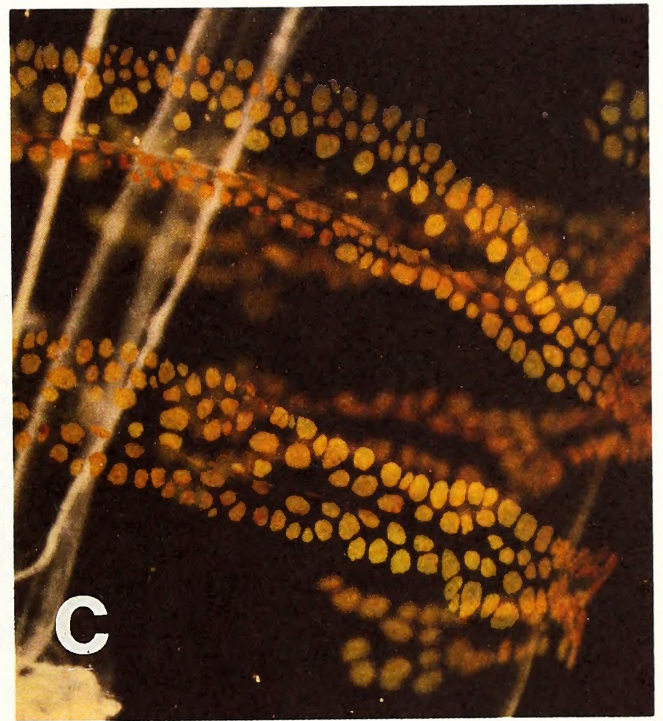
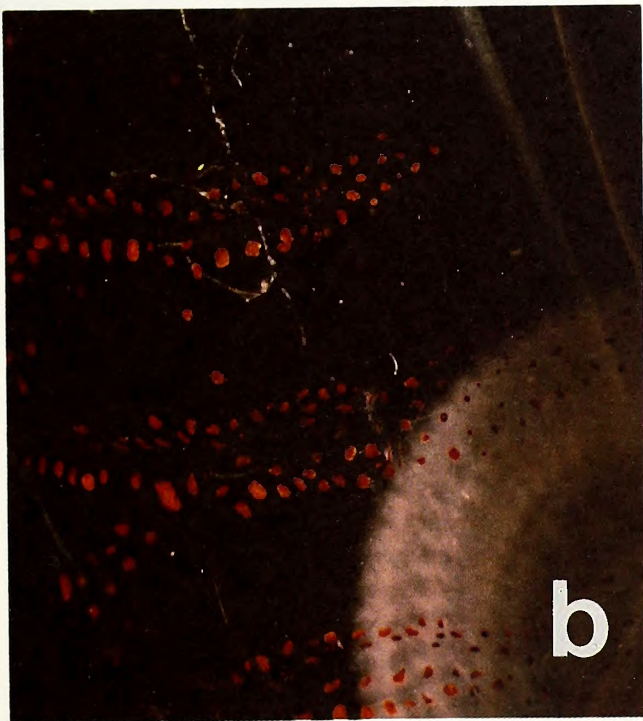


Figure 1. The solitary salp, *Ihlea punctata*, has three bands of pigment spots surrounding the body. At night, the spots contract (a, b), and during the day they expand (c). These chromatophores make this otherwise transparent animal much more conspicuous, and undoubtedly serve to attract or repel some animal with image-forming eyes. All photos are of the same animal, which is about 6 cm long.

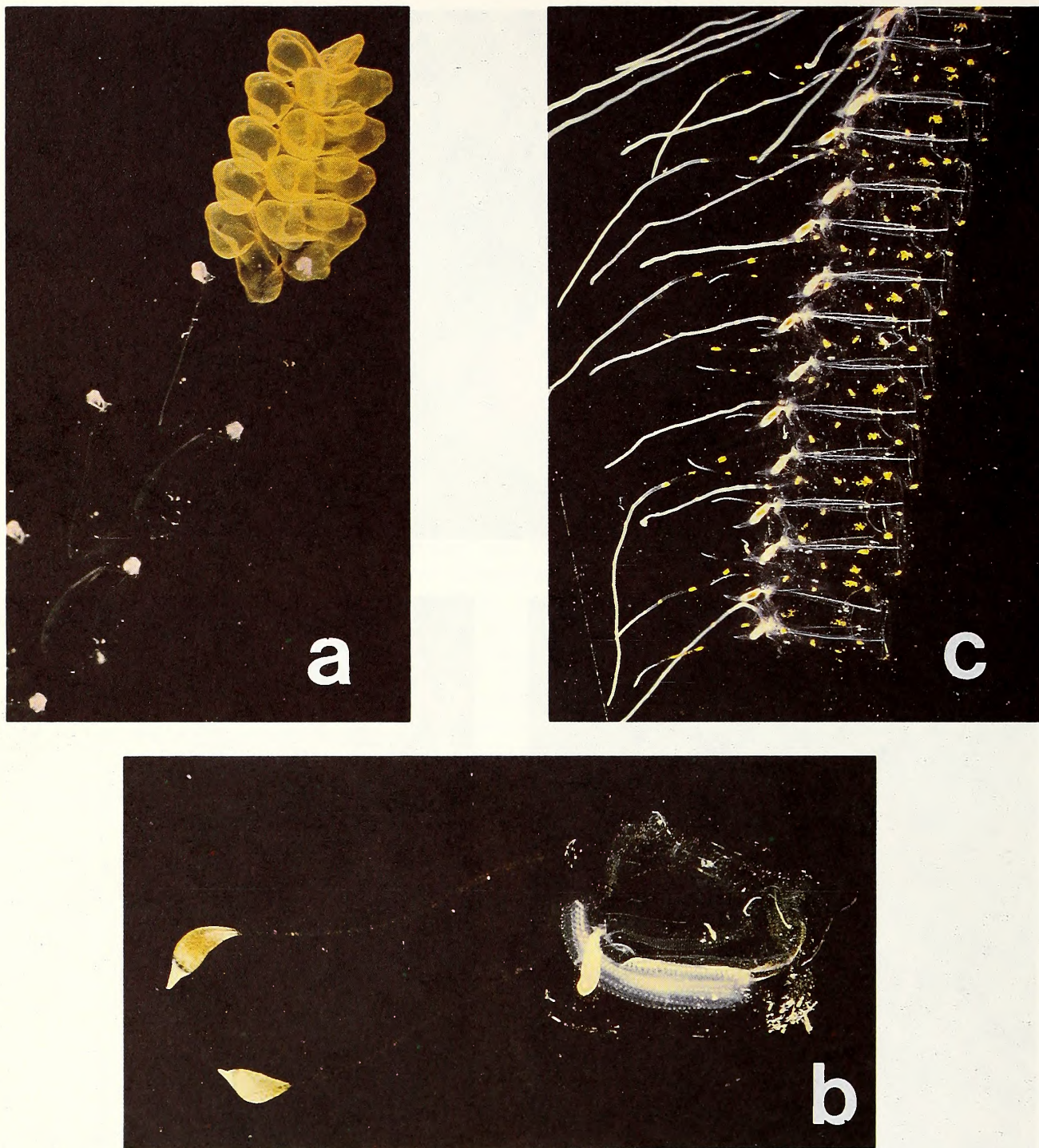


Figure 2. Examples of conspicuous pigmentation in salps: (a) The eight aggregate *Ritteriella amboinesis* (each about 2 cm long) are barely visible, but the yellow "tail" makes them stand out. (b) The solitary *Traustedtia multitentaculata* has two "tails," while (c) the aggregates are covered with yellow spots as well. Fifteen aggregates are in Fig. 2c, each about the same size as the solitary (ca 1.5 cm).

squids. Although there are gelatinous organisms living in lakes and near the shore, it is the open sea where these animals attain their greatest abundance and diversity. Because of their fragility, they do not take well to areas with much mechanical stress, so most of the names I have listed are unfamiliar, even to biologists. Yet these exotic animals are among the most abundant large animals on Earth, and are exotic only because one must go to sea in order to study them.

The first tools that were used to study life in the open sea were towed nets, and the towed net is still the most popular collecting device today among plankton biologists. Although nets can give a great deal of information, especially about organisms that are rugged enough to withstand mechanical stresses, they do not work very well with the gelatinous forms. To give an example, in May 1983, I had the opportunity to use the JOHNSON-SEA-LINK to collect ctenophores. On a single 10-day cruise in the Bahamas, I collected nine different species of ctenophores, living at a depth of 2000 ft -- one species had not been reported since its original description, two species had been previously described from the deep sea by L. P. Madin and myself, and five were altogether new (two of these new species are new genera). During this cruise to one small area in the North Atlantic, the known deep-sea ctenophore fauna was doubled! Based on these collections, I have come to the belief that most ctenophores are probably inhabitants of the deep ocean, and are yet to be described.

As far as ctenophores are concerned (and probably a number of other gelatinous animals as well), plankton ecology is entering a period resembling that of the early Nineteenth Century. As we explore the deep sea for the first time, we encounter a fauna whose presence was previously unknown (Fig. 3, for example). Our first task is to describe the diversity of life we encounter, so that we can move on to the science of the Twentieth and Twenty-first Centuries. For other animals, which have been collected with nets, there has been little progress since the latter part of the Nineteenth Century, because the nets that are used today, though considerably improved with sophisticated electronic devices, are still essentially the same as the gear used a century ago. The data are better, and there is a lot more environmental information, but the questions are still the same as those posed by Nineteenth Century plankton biologists (see Haeckel, 1893; Murray and Hjort, 1912). Areas of research that have remained essentially unchanged after more than a century are such topics as the vertical distribution of the plankton, the relationship of faunal composition to water masses, plankton patchiness, and the significance of the co-occurrence of various species in net collections. Field observations, directed sampling, field experiments and, above all, the study of the behavior of undisturbed animals in their own environment, all of which have radically changed the nature of terrestrial ecology, are just beginning to have an effect on the way plankton biologists think about their field.

Since collecting with towed nets gives little information about what the animals were doing prior to capture, most plankton biologists are concerned with only the grossest aspects of behavior (such as relating distributions of animals to temperature or food abundance, or inferring feeding strategies from analysis of gut

contents). Others try to reconstruct behavior in the field from morphology and laboratory studies on those few animals hardy enough to survive the net collection. A good analogy that might be used to see the pitfalls in this approach is to imagine what an ecological study on hummingbirds might be like if the sole means of studying them were with nets towed from helicopters. First, since few hummingbirds could be collected in such a way, obtaining statistically significant counts would be difficult. Very few would be collected in association with flowers, and the only recognizable material in their stomachs would be insects, since the nectar could easily be undetected. If some animals survived the collection technique, it

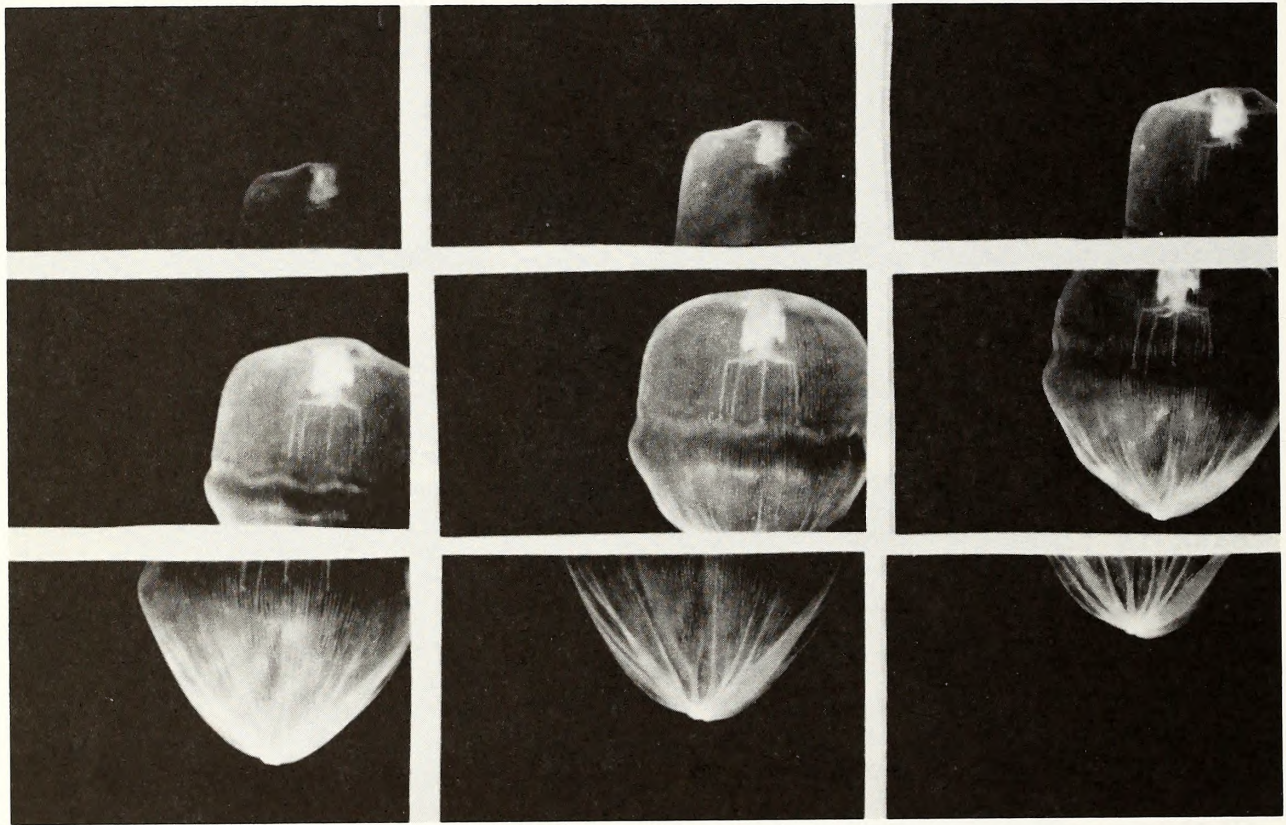


Figure 3. An animal photographed at about 600 m off San Diego, California by the Edgerton camera of the DSRV ALVIN. Each photograph is taken at 4-second intervals. This animal, about the size of a basketball, could be the jellyfish Deepstaria enigmatica Russell. When first seen, it resembled a lampshade, and when it encountered the turbulence from the submersible, it pursed its lower end, and a peristaltic wave of contraction moved up the body. Note the five "hooks" hanging in the center of the animal, and that there is no trace of tentacles on the margins of the bell. It is extremely difficult to imagine how this animal captures prey in midwater.

might be possible to feed them insects in the lab, and measure their growth and metabolism, constructing a very plausible scenario about how they live without any reference to flowers! Of course, we know that such a scenario is absurd, and the reason we know this is that we can directly observe both hummingbirds and flowers. Direct observation on planktonic animals is not so easy, so we probably still have many absurd ideas about the way these animals live, based on methods similar to those in the analogy above.

To cite a few examples, direct observation quickly established that the picture previous plankton biologists drew of the lives of shallow-living hyperiid amphipods, while plausible, was wrong. These animals had been regarded as free-swimming zooplankton, but in actuality they are parasites of gelatinous zooplankton (often quite specific parasites). A good case in point, directly comparable to the "hummingbird" analogy, is that of the hyperiid amphipod, Vibilia, a specific parasite on salps. This amphipod eats the food string of its filter-feeding host, so that the material in its gut is identical to the gut contents of a salp (Madin and Harbison, 1977). If we did not know, from direct observation, the way Vibilia lives, we could be easily misled into thinking that it was a free-living filter-feeder. In the same way, other hyperiid amphipods, which steal food from predatory gelatinous hosts, such as jellyfish and siphonophores, were previously considered as free-living predators, until direct observation showed the true state of affairs (Harbison et al., 1977). By observing them in the field, it was also easy to see that shelled pteropods feed with external mucous webs, and are neutrally buoyant in the water, contrary to earlier speculations (Gilmer and Harbison, 1986). I could give a number of other examples as to the way that direct observation has changed our conceptions about other zooplankton, such as copepods, medusae, siphonophores, salps, colonial radiolarians, larvaceans, phytoplankton, and even marine snow. It should be noted that the first (and until recently, best) reports on marine snow were based on direct observations from a submersible (Nishizawa et al., 1954).

Hoping that I have convinced you that direct observation holds the key to changing the very nature of plankton biology, or at the very least provides vitally-needed information about how planktonic animals live, the question remains, how do we go forward in exploring deeper parts of the ocean?

At present, the JOHNSON-SEA-LINK (JSL) is the best submersible for plankton studies. It has unrivalled visibility and superb collecting devices. Its major limitations are that it is large, and uses powerful lights in order to see the animals living in midwater. It is obvious that both of these factors could disturb many midwater creatures, but it is also likely that many animals will not be affected very much at all. While we should continue to develop methods to decrease the disturbance caused by our techniques of observation, by using smaller submersibles, night-viewing devices, etc., we should continue to study those animals we can with existing technology.

For the future, the direction is clear, and that is to spend more and more time in the field, at greater and greater depths. As I have stated previously (Harbison, 1983), the ultimate goal is an undersea research vessel that will allow biologists to spend all of their time while at sea conducting in situ research. Such a vessel

could lock out divers and small submersibles for collecting, close-up observations and directed sampling. We have spent enormous sums on close-up investigations of other planets, and it is now time to think about how we can also make close-up observations in the largest and most alien place we have here on our own planet, the open sea.

ACKNOWLEDGEMENTS

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BIOLOGICAL AND TECHNICAL OBSERVATIONS OF HALIBUT LONGLINE GEAR
FROM A SUBMERSIBLE

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ABSTRACT

The submersible Nekton Gamma (1978, 1980, 1982) and Mermaid II (1983) were used to conduct studies associated with halibut longline gear in Alaska coastal waters. Several bait types were tested for durability on hooks and attractiveness to fish. Traditional "J" type hooks and newly introduced "circle" type hooks were compared for catch and escape rates. Also, a wide range of incidental observations on fish and crab behavior and fish habitat were made. An initial review of the data has produced the following results: a future report will include a more comprehensive analysis. Less than 20% of herring bait remained on hooks after 2-hours while about 80% of octopus bait remained. Salmon bait was superior to all others tested. Because of rapid bait loss, half the halibut were hooked within the first 2-hours of soak and less than 10% of the catch were hooked after 6-hours of soak. Circle hooks were far superior to traditional hooks partly because they permitted fewer fish to escape. Circle hooks captured 60% more halibut, 130% more rockfish (Sebastes) and 100% more miscellaneous species. Small synthetic plastic floats placed near the baited hook to float it above bottom dwelling predators did not provide sufficient buoyancy at fishing depths.

INTRODUCTION

Catch per unit effort (CPUE) is one measure used to assess resource condition and size. While it is a useful tool for monitoring the Pacific coastal halibut fishery, it is recognized that halibut demersal longline gear effectiveness is influenced by such factors as how fishermen rig and set their gear, how the hook types are baited and with what type of bait, how long the gear is left on the bottom (soak) before it is retrieved, and other parameters.

A submersible was chartered over several years by NOAA's Office of Undersea Research (OUR), and in cooperation with the International Pacific Halibut Commission (IPHC), the NMFS conducted a series of experiments to learn more about halibut longline gear (High, 1980). Our objectives included:

- 1) A study of common baits used, their attractiveness and rate of loss,

- 2) a comparison of the catching and holding power of the traditional "J" type hook and a newly introduced "circle" type hook,
- 3) determining the effect of soak time,
- 4) in situ observations of fish and gear behavior, and
- 5) viewing the effectiveness of commercially made floats designed to hold the ganglion and baited hook off the sea floor.

METHODS

Operations over the four years were similar although fishermen, some submersible crews, and investigators changed. Our goal was to reach the demersal longline gear as quickly after it was set as submersible launch and safety considerations allowed, generally in 20 to 40 minutes. The gear was located by descending adjacent to the buoyline or by tracking a self-contained battery-powered acoustic transmitter attached to the groundline (Figure 1).

Investigators attempted to view each hook and voice record its status on magnetic tape for later transfer to permanent data

LOGLINE FISHING SYSTEM (side view)

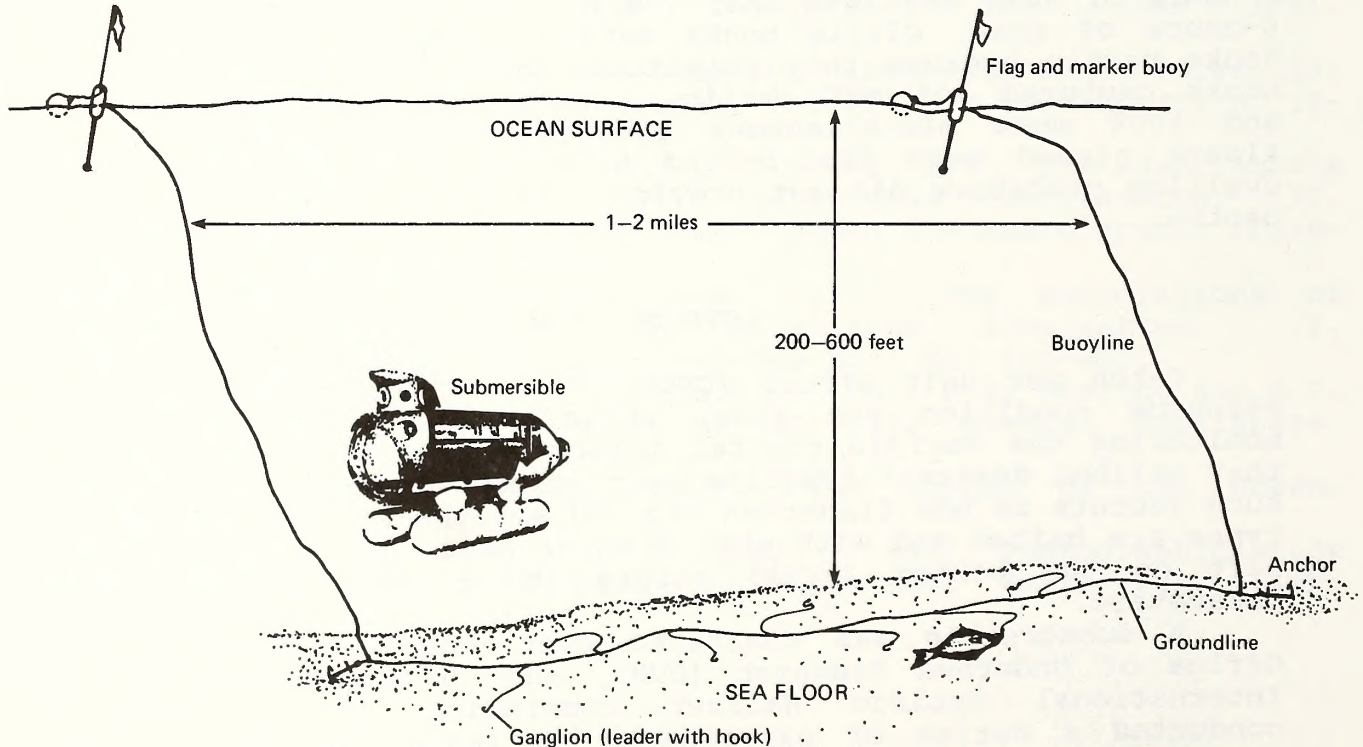


Figure 1. Schematic view of longline fishing system.

sheets. Reference numbers were attached to the groundline about every 10 hooks. Upon reaching the end of the longline, the submersible either retraced its trackline for short interval observations or surfaced to allow additional soak time before collecting the next data set.

Submersible Systems:

The submersible Nekton Gamma was leased in the years 1978, 1980 and 1982. Chartered commercial king crab fishing vessels F/V Antares (1978) and F/V Gold N Cloud (1980, 1982) transported the submersible on deck to dive sites. Launches and recoveries, using deck-mounted hydraulic cranes, were made over the vessels' side.

During 1983, the submersible Mermaid II was supported by its mothership, M/V Aloha which handled the submersible over its stern on a large gantry. Although the M/V Aloha worked best because of its permanent support status, both fishing vessels, each in excess of 125 ft (38 m), had ample open deck space for all operations and they both had the additional advantage of routinely handling king crab pots used during some underwater studies. Both Nekton Gamma and Mermaid II operated to 1,000 ft (304 m). However, during portions of the cruises devoted to longline studies, longline gear was generally observed on commercial fishing grounds at depths less than 600 ft (183 m).

Each submersible carried a single science observer in addition to the pilot. The Nekton Gamma observer viewed the sea floor and longline gear from either of two 4" (10 cm) diameter flat ports located on the hull's side. Forward directed ports were useless for viewing because of a permanent coating of hydraulic fluid from leaking mechanical arm lines. The pilot's view through numerous conning tower ports was essentially independent of the scientists' view. Mermaid II, on the other hand, utilized a forward directed 30" (76 cm) viewing hemisphere. Both scientist and pilot lay side by side, sharing a wide view forward and to each side.

Longline Gear:

Demersal longline fishing gear observed each study year from different fishing vessels was similar since North Pacific U.S. halibut gear has been fairly well standardized over many years. The groundline was 9/32 inch (.6 cm) treated nylon. Three foot long gangions (leaders) of No. 72 thread nylon were attached with 5 inch long (12.7 cm) gangion snaps to the groundline at about 12-15 ft (3.6-4.6 m) intervals as the groundline was set over the vessel's stern. Traditional "J" type hooks (Figure 2), Mustad 6283¹ were studied until 1983 when the newly introduced circle hooks (Figure 2), Mustad 39965 ST-3 were included. Except for a few traditional 250 fathom (458 m) groundline skates fished from the R/V John N. Cobb in 1978 and the R/V Thor in 1982, all observed gear was fished from the commercial snap gear longliners F/V Crusader, F/V Tiffy and F/V China B. Bait size was selected by the fishermen but type and sequence of set was prescribed by the science team. Each hook was observed for appropriate data as

¹Use of brand name does not imply endorsement of the product.

the gear was retrieved. Halibut were measured immediately upon landing and other species identified.

Comparing Bait:

Most bait studies were carried out using the standard "J" hook with test baits alternately placed along the groundline. Although the method has limitations, including the possible overlapping attractiveness of one bait type to the other, rapidly changing bottom type with resulting change in abundance of fish and predators impacted less with this method. Two baits, salmon and octopus, were compared during 1983 on the more successful circle type hook. Each bait in groups of 10 hooks were placed alternately along a groundline (Finley, 1984).

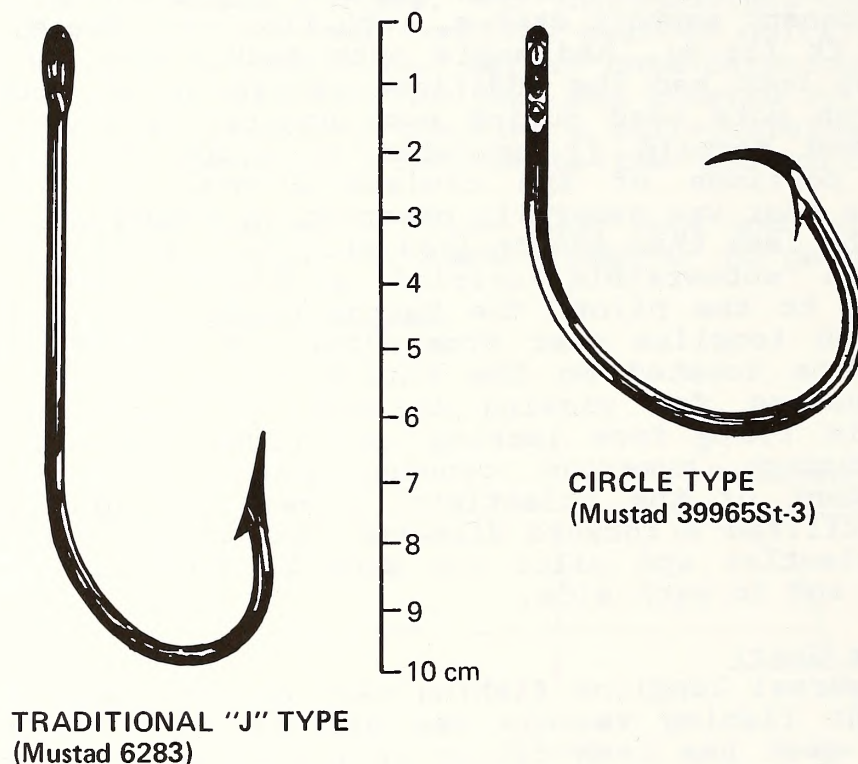


Figure 2. Hook types compared for catch and escape.

RESULTS

Bait Loss:

Loss of bait from hooks with soak time varied widely between bait types. Bait toughness, attractiveness, sea floor type and type and abundance of predators all contributed to bait loss. Of the baits tested, herring disappeared so rapidly it was difficult to estimate the rate. If we assume, as other studies show (Skud and Hamley, 1978), bait loss from the gear setting process to be low, then in general, 80 to 90% of herring baits were removed

(10 to 20% retained) within an hour by striking fish and the many predators found on most bottom types. Salmon bait likewise was aggressively attacked. Its tougher skin, fins and bones contributed to a 60% retention rate after 1 hour and 40% after 2 hours.

Both Pacific gray cod and octopus baits remained on the hooks for longer periods. Contributing to this retention was the apparent lack of interest in the bait by invertebrates such as snails, starfish, shrimp and crab. Herring and salmon baits by contrast were commonly covered with feeding invertebrates. In Frederick Sound, Alaska, in 1978, about 80% of the octopus baits were present after nearly 3 hours in spite of the presence of many predators. In 1983 near Sitka with many halibut present, 50% of the octopus baits remained in the same time period.

Because of the rapid loss of bait, half the halibut observed hooked during 1983 dives were taken within the first 2 hours of soak and less than 10% of the catch were hooked after 6 hours of soak.

Bait Attraction:

Obviously some baits were more attractive than others to fish and unwanted invertebrates. Bait loss rates reflect this as do fish catch rates. Both salmon and herring baits, while on the hook, caught more halibut than did either Pacific gray cod or octopus. Few Pacific gray cod or octopus baits were observed under attack by invertebrate predators.

Salmon bait was clearly superior to octopus when over 500 circle hooks having each of these baits were compared in alternate groups of 10 baits along the groundline. Thirty-three percent of those hooks with octopus bait had halibut as did 39% of salmon baited hooks. Importantly, the difference in proportion of these catches is 20% greater for salmon, a bait far less durable than octopus.

Rockfish (mostly Sebastes ruberrimus) taken incidentally during the salmon and octopus bait experiment occupied 15% of each bait type hook, thus this species seemed to have no preference between the two baits. Surprisingly, other species, mostly ling cod (Ophiodon elongatus) occupied 1% and 2.8% respectively, of the octopus and salmon baited hooks, a proportional increase for salmon of 180%.

Comparing Circle and J Type Hooks:

Nearly 1,400 circle and J hooks were set alternately and compared for catch. All baits (herring, salmon and octopus) and soak times were combined. Results are shown in Table 1.

Halibut Escape from Hooks:

The submersible clearly was an excellent means to observe escape of fish from hooks. Once observed hooked, the presence or absence of a fish was confirmed on later dives or when the appropriate hook was retrieved aboard the fishing vessel. Prior to 1983, halibut escape rates from J hooks varied between 5 and 50% with an average of about 19%.

Table 1. Comparison of longline catch from 1,387 circle and 1,394 J type hooks.

Species	Catch Circle Hook	% Total C Hooks	Catch J Hook	% Total J Hooks	% Increase Proportion on Circle Hooks
Halibut	256	18.5	157	11.3	63.7
Rockfish	252	18.2	109	7.8	133.3
Other fish	31	2.2	16	1.1	100.0
Total Hooks Occupied by Fish	538	38.9	282	20.2	92.6

In 1983, nearly 1,400 circle and J type hooks were compared for halibut escape. Of the 276 halibut which occupied circle hooks, 20 (7.2%) escaped. Of the 1975 halibut which occupied J hooks, 18 (10.3%) escaped. These escape rates although somewhat lower than the average in prior years show the escape rate of halibut to be 47% higher from J hooks than from circle hooks. Obviously, this difference contributes to the overall better performance of circle hooks.

Size of Fish by Hook Type:

Investigators, most of whom had scuba diving experience, developed a moderate skill at estimating the size of halibut viewed through the flat ports of Nekton Gamma. Initial efforts to estimate halibut size through the large hemisphere port of Mermaid II in 1983 were unsuccessful. Distortion caused fish to appear much smaller than actual size.

Although we were not able to accurately estimate the size of those which escaped from hooks in 1983, thereby learning if escape was related to size, Steve Hoag, IPHC, was able to measure all hooked halibut which came aboard the fishing vessel (Figure 3). It appears somewhat smaller fish were taken by the circle hook.

Incidental Observations:

Initially, at 200 to 500 ft depths, the commercially made plastic gangion floats were not sufficiently buoyant to lift either hook or bait above the sea floor. After several exposures to these fishing depths, the floats lay useless on the bottom.

Hooked fish frequently had others of the same or different species hovering nearby. Sometimes a rockfish attempted to steal the partially exposed hook or bait from a hooked fish and also became hooked. This attraction to hooked fish may contribute to

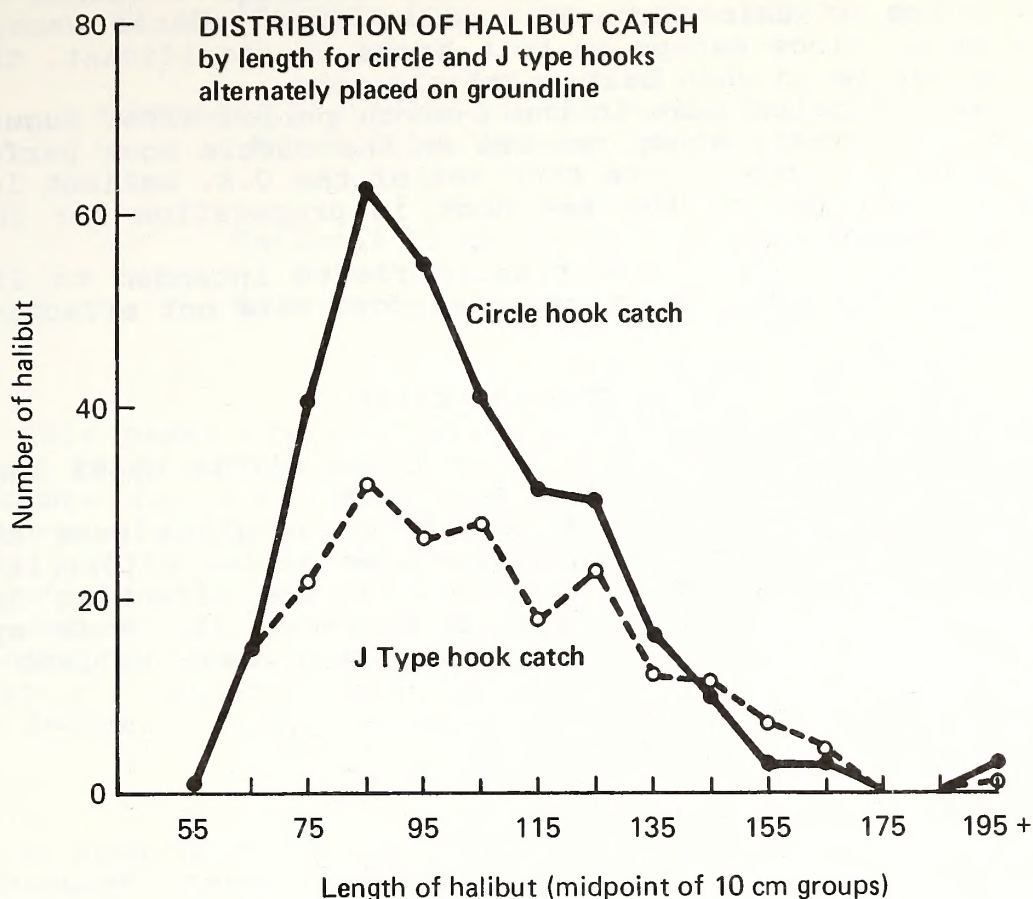


Figure 3. Distribution of halibut catch by length for circle and "J" type hooks alternately placed on groundline.

the observation that halibut are not hooked randomly along the groundline.

From time to time in each study year, halibut were occasionally observed on hooks previously observed to be on the sea floor without bait. We had no explanation but considered errors in data collection were unlikely at the observed frequency. Fortunately, in 1983 one investigator observed a halibut attack an empty hook, thus becoming hooked.

Ken Parker, IPHC, documented on cine film most aspects of the 1983 research effort. From this footage, a descriptive 15 minute sound film was produced by NOAA. Copies in 16 mm and VHS video cassette formats are available from Camera One Productions, Seattle, WA.

CONCLUSIONS

Herring is an adequate halibut bait only for very short period soaks. Salmon bait is probably superior to all others during soak times up to 3 hours. Octopus should be one of the baits used when long soaks are necessary.

Circle hooks produce many more, although somewhat smaller halibut. Some of this increase results from reduced escape from the new hook. Since escape on both hooks is significant, the gear should be retrieved when bait is mostly gone.

It is estimated that in the 6-month period after August 1983 when our preliminary study results on the circle hook performance became generally known, more than 90% of the U.S. halibut longline fishermen converted to the new hook in preparation for the 1984 spring fishing season.

Small commercially made plastic floats intended to lift the baited hooks above the sea floor predators were not effective.

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LONG-TERM OBSERVATIONS ON THE BENTHIC BIOLOGY AND ECOLOGY
OF AN OFFSHORE DIVE SITE IN THE GULF OF MAINE

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ABSTRACT

This paper presents the results from a long-term study of a boreal hard bottom benthic community. The community population structure was first described by disruptive collection of 0.25 m² areas of benthic flora and fauna. Dominant species, analyzed from photographs, were selected for long-term monitoring. Population densities of ascidians, sea stars, and brachiopods have been determined yearly from 1978 to 1983 by the use of in situ photography. Ascidians have had a fluctuating population of 3 to 23/.25 m², sea stars have increased from 4 to 39 and brachiopods have decreased from 44 to less than 1.

INTRODUCTION

A program to monitor the health of the continental shelf environment, namely the Northeast Monitoring Program (NEMP), was established by the National Marine Fisheries Service (NMFS) in 1978. This program used a variety of scientific disciplines to assess the nature and extent to which our marine environment has been or may be affected by pollution. As part of this program the Manned Undersea Research and Technology (MURT) program of the Northeast Fisheries Center (NEFC) began a research project in 1978 using in situ diving techniques to determine benchmark population densities and pollutant body burdens of dominant macrobenthic species at sites along the New England coast, on Georges Bank and the Georges Bank submarine canyons (Figure 1). The MURT sites were complementary to the overall NEMP coverage and represent areas difficult to sample with conventional surface techniques. Nearshore hard bottom substrates, with attached flora and fauna that can be most effectively studied and sampled in situ by divers are the subject of this paper.

Pigeon Hill (Figure 1, Station 1) on Jeffreys Ledge in the western Gulf of Maine was selected as a study area for its pristine nature, accessibility by scuba, and background of study. The biology and geology of Jeffreys Ledge (major herring spawning grounds) has been a subject of study by us and other scientists since 1971. Surveys of herring spawning areas there have been discussed by Cooper et al. (1975) and the biology and geology by McCarthy et al. (1979), Sears and Cooper (1978), Witman et al. (1980), Pecci and Hulbert (1981), Hulbert et al. (1982), and Witman and Cooper (1983). Pigeon Hill is a hard substrate undersea knoll at a depth of 33 meters with a complex community

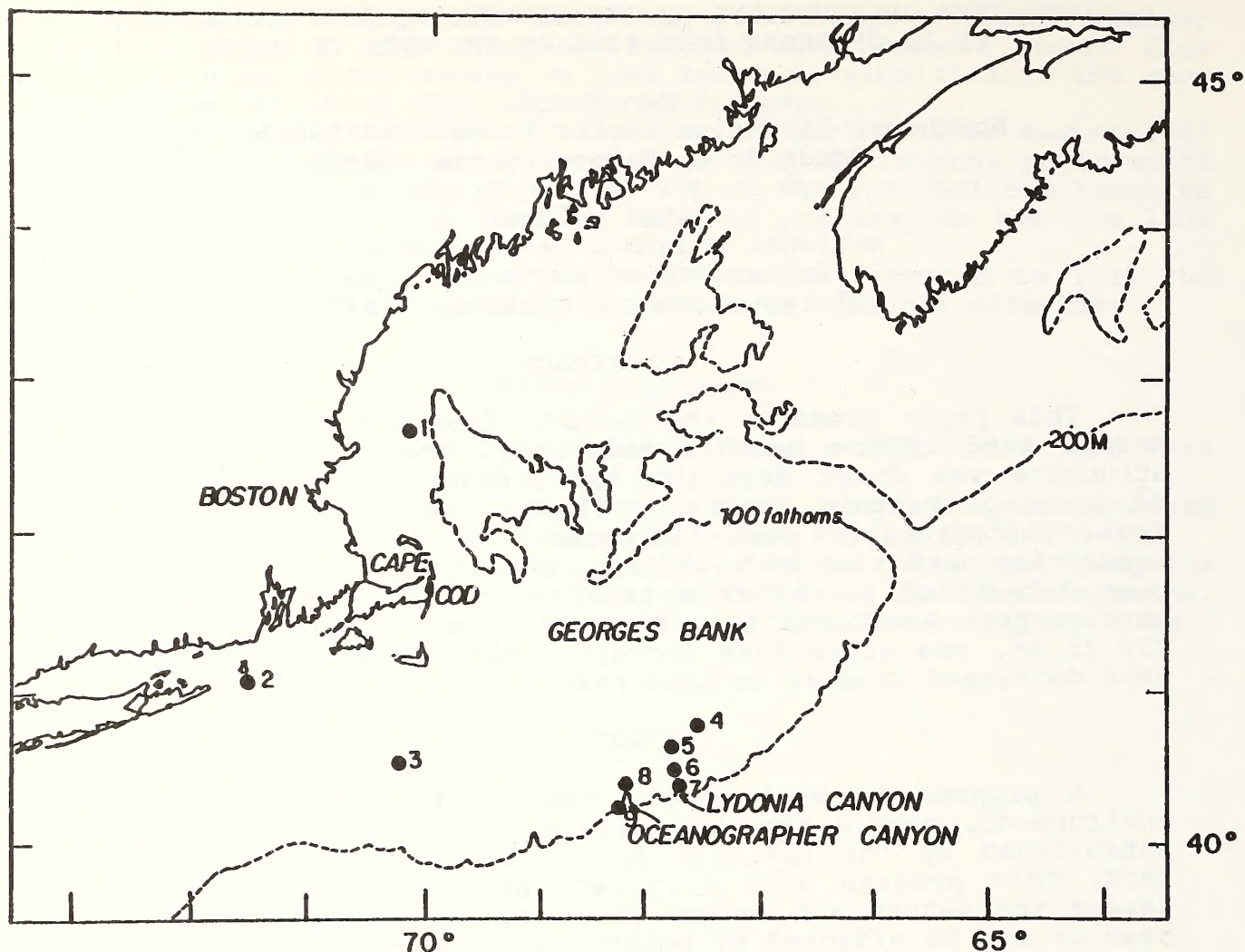


Figure 1. Chart of the New England Continental Shelf showing inshore and offshore Northeast Monitoring Program study sites revisited annually by the NMFS dive team.

of flora and fauna typical of boreal benthic communities north of Cape Cod, and because of its isolation the benthic community is relatively unimpacted by pollution sources.

Three numerically dominant species are discussed, using long-term (1978-83) population estimates: ascidians (*Ascidia callosa*), sea stars (*Henricia sanguinolenta*) and the brachiopod *Terebratulina septentrionalis*. We will discuss a precipitous decline in the density of *Terebratulina*, a corresponding increase in sea star density, and the association between brachiopods and the encrusting sponge *Iophon nigricans*.

MATERIAL AND METHODS

We began the Pigeon Hill monitoring study by defining a quantitative baseline of benthic inhabitants from in situ photographic transects made from 1978 to 1983. With these

photographs we monitor the density of "indicator species" selected for their numerical abundance, photographic affinities, and trophic level. Information on the indicator species is then considered as reflective of the dynamics within the ecosystem (biotic and physical environments) (Paine, 1976; Hulbert 1980a, 1980b, 1981). Additionally, indicator species were analyzed for body burdens of heavy metals, petrogenic hydrocarbons, and polychlorinated biphenyls.

The initial site descriptions were obtained from disruptive collections of 0.25 m² of ocean floor. Random 0.25 m² quadrats on both horizontal and vertical substrate surfaces were first photographed, then disruptively sampled and subsequently re-photographed. The work surfaces were scraped with a putty knife and the organisms collected with an airlift into a 1-mm mesh bag, brought to the surface, labeled and preserved. Subsequently samples were sorted by species, and data on density, size, and biomass were recorded.

Permanent transects 30 meters in length were established on both horizontal and vertical surfaces at Pigeon Hill in 1978. These sites have been revisited by scuba divers yearly for rephotography of the benthic community by consecutive 0.25 m² quadrats. From these photographs we derive counts of indicator species and note changes in the ecological components of the benthic community.

Sequential 0.25 m² quadrats of bottom were photographed by divers using a Nikonos underwater 35 mm camera equipped with a 15 mm lens. The camera is positioned 0.5 m off the bottom in an aluminum frame, and records the area within a 0.5 m by 0.5 m square. This non-destructive sampling allows resampling of sites not disturbed by previous study.

RESULTS AND DISCUSSION

A total of 149 benthic species have been identified from the Pigeon Hill disruptive samples. The species comprise two ecologically distinct benthic communities: an algal-polychaete community and a sponge-tunicate community. The local distribution of the two major communities is determined by substrate angle. The algal-polychaete community is dominant horizontal rock surfaces and the sponge-tunicate community is restricted to vertical rock walls.

The common species of the algal-polychaete community are the red algae Ptilota serrata, the sabellid polychaete Chone infundibuliformis and the terebellid polychaete Thelepus cincinnatus. Ptilota averaged 66% coverage of horizontal surfaces, and the mean densities of Chone and Thelepus were 254 and 164 individuals/0.25 m², respectively. Ptilota, Chone, and Thelepus form an important three dimensional habitat providing a secondary substrate on horizontal rock surfaces. Ptilota is an upright algae with a branching form and both Chone and Thelepus are tube dwellers that construct a matrix of tubes several centimeters thick. The tubiculous amphipods Corophium crassicorne, Ischyrocerus anquipes and Haploops tubicola also form

part of this tube matrix. A diverse invertebrate fauna inhabits the tube matrix complex including amphipods, caprellids, small asteroids, ophiuroids, brachiopods, and ectoprocts. Ophiuroids are a common group associated with the horizontal surface community; Ophiura robusta had a mean density of 447/0.25 m² and Ophipholis aculeata a density of 137/0.25 m². Crustose coralline algae also occur on horizontal rock surfaces.

The vertical substrate is virtually free of sediment. Ptilota is nearly absent from the sponge-tunicate dominated vertical community. Crustose coralline algae are common on vertical surfaces in conjunction with sponges, tunicates and brachiopods. The sponge component of the community is represented by at least nine species, although the actual number of species that occur at Pigeon Hill is probably several times greater. The sponge colonies have several major growth forms: (1) the thin, sheetlike encrustations of Hymedesmia sp. and Halichondria panicea, (2) the rounded globose form of Myxilla fimbriata, Plocaminonida ambigua and Iophon pattersoni, and (3) the upright branching form of Haliclona palmata and Haliclona oculata. The mean percent cover by sponges was 17.3% and tunicates covered 6% of vertical surfaces. The tunicate fauna is represented by at least seven species with the most common being Ascidia callosa.

In summary, the horizontal communities are dominated by fleshy algae and a polychaete tube matrix which provide vertical structure, secondary substrate and trap sediment. Vertical communities are dominated by the colonial growth forms of sponges and tunicates which trap little sediment and have few secondary encrustations.

The long-term monitoring of indicator species by rephotographing transects has been done for six years (1978-83). The abundances of the indicator species, asteroids (Asterias vulgaris, Henricia sanguinolenta, Leptasterias sp., and Stephanasterias albula), ascidians (Ascidia callosa), and brachiopods (Terebratulina septemtrionalis), on our permanent vertical transects are given in Table 1 and, on horizontal transects in Table 2. Asteroid density increased between 1978 and 1981, then stabilized at about 40/0.25 m² on vertical surfaces and 10-20/0.25 m² on horizontal surfaces. The vertical surfaces reflect a more accurate count of individuals present since the absence of an algal mat aids in detectability. Ascidians, common residents of vertical surfaces, had a fluctuation in population but have ranged from 5-20/0.25 m² with an increase in 1983 to 22/0.25 m². The 1983 increase was due to juveniles. Brachiopods, dominant on vertical walls, continued to decline from a 1978 level of 44.2 to 0.3/0.25 m² in 1983 and are now nearly absent from the permanent transects. There was less than 2% fleshy algal cover on vertical transect surfaces, although coralline algae covered significant amounts of area.

The densities of brachiopods and sea stars on the vertical transects have had an inverse relationship throughout the period of study (1978-83). Asteroids had an average density of 3.7/0.25 m² in 1978, increased to 14.7 in 1979 and 37.6 in 1980, then dropped in 1981 to 14.0 and rose to 38.9 in 1982 and 39.2 in 1983. At the same time brachiopod densities demonstrated a steady decline from 44.2 in 1978 to 0.3 in 1983.

Table 1. Abundance of indicator organisms from 0.25 m² quantitative photographs along permanent transects on vertical surfaces at Pigeon Hill.

Asteroids (#/.25 m²)

<u>Date</u>	<u>\bar{X}</u>	<u>S.D.</u>	<u>N</u>
9/78	3.7	2.5	53
9/79	14.7	8.5	50
6/80	37.6	17.9	51
3/82	40.3	10.3	27
6/82	38.9	17.5	36
6/83	39.2	10.4	62

Ascidians (Colonies/.25 m²)

<u>Date</u>	<u>\bar{X}</u>	<u>S.D.</u>	<u>N</u>
9/78	5.0	6.9	53
9/79	14.1	8.0	50
6/80	3.0	1.2	51
6/81	7.8	4.5	43
3/82	16.1	12.8	27
6/83	22.8	17.3	62

Brachiopods (#/.25 m²)

<u>Date</u>	<u>\bar{X}</u>	<u>S.D.</u>	<u>N</u>
9/78	44.2	19.2	53
9/79	56.1	20.2	50
6/80	28.7	16.3	51
6/81	5.9	6.0	43
3/82	5.6	4.4	27
6/82	1.5	2.2	36
6/83	0.3	0.7	62

The reason, at least in part, for the precipitous decline in the density of Terebratulina is due to predation by sea stars. Diver observations and in situ photographs confirm Terebratulina is a food source for asteroids. Asterias vulgaris was observed by divers in a typical hunched feeding posture on a brachiopod at our transect. Witman and Cooper (1983) state from their diving observations and collections at Pigeon Hill, that cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) were never observed feeding on vertical rock wall benthos. They also conclude that Terebratulina living on rock walls were not affected by drilling predators, but they did observe Leptasterias sp. feeding on Terebratulina. In view of these observations, combined with ours, sea star predation may be the major cause of predator-induced mortality of brachiopods at our study site.

Terebratulina has one major epibiotic, the encrusting sponge Iophon nigricans. Our initial survey in 1978 found 57% of

Table 2. Abundance of indicator organisms from 0.25 m² quantitative photographs along permanent transects on horizontal surfaces at Pigeon Hill.

Asteroids (#/.25 m²)

<u>Date</u>	<u>X</u>	<u>S.D.</u>	<u>N</u>
9/78	0.6	0.9	55
9/79	2.1	1.8	61
6/80	4.6	3.2	60
6/81	10.8	4.5	68
9/81	27.0	9.9	26
3/82	19.7	7.5	34
6/82	13.5	7.3	64
6/83	10.7	4.6	63

Ascidians (Colonies/.25 m²)

<u>Date</u>	<u>X̄</u>	<u>S.D.</u>	<u>N</u>
9/78	0.0	0.0	55
9/79	0.5	0.9	61
6/80	0.2	0.5	60
6/81	1.0	1.2	68
9/81	0.2	0.6	26
3/82	0.2	0.4	34
6/82	0.2	*	64
6/83	0.1	0.9	63

Brachiopods (#/.25 m²)

<u>Date</u>	<u>X̄</u>	<u>S.D.</u>	<u>N</u>
9/78	3.0	3.0	55
9/79	4.7	5.9	61
6/80	3.7	3.6	60
6/81	0.4	1.1	68
9/81	0.5	0.8	26
3/82	0.4	1.0	34
6/82	0.3	0.7	64
6/83	0.0	0.1	63

Terebratulina to be associated with Iophon. Encrusted and nonencrusted individuals often resided adjacent to each other. During our most recent survey (1983), only 19 Terebratulina remained on the transect and, all were covered by sponge material. This high observed proportion (χ^2 - test, $P < 0.01$) of encrusted individuals may be due in part to a protective advantage gained by having epibiotic growth. Vance (1978) observed the shell of the jewel box clam, Chama pellucida, to "normally be covered by a dense growth of sessile plants and animals of phyla. Removal of these epibionts seems to make detection and/or attack of Chama by the predatory starfish Pisaster giganteus more often successful in the laboratory and substantially increases Chama mortality through Pisaster predation in the field." Bloom (1975) found sponge

covering on scallop shells to be a protection from predatory starfish by altering the surface texture of the shell and decreasing the adhesive abilities of asteroid tube feet. We feel the survival of the limited number of encrusted brachiopods at our site may have also been due to the protective advantage of sponge encrusting material.

CONCLUSIONS

Natural populations of marine organisms have two causes of fluctuations in their densities: (1) the effect of their own natural environment on reproduction and mortality and (2) man's effect on their numbers either directly by harvesting or indirectly by environmental changes such as temperature, disruption of habitat or, the introduction of pollutants. To assess the extent of population changes from man's influence, the extent of changes from natural causes must be taken into account. One purpose of this benchmark/monitoring study was to determine this natural variability in a resident benthic population.

In our case there was an extensive decline in the brachiopod population (probably from sea star predation), a rise in sea star density and a yearly variability in ascidian abundance. The natural dynamics of this marine environment complicate the ability to estimate the effects of man's influence over a long term, but, if a yearly photo-survey is done, any immediate impact can be determined.

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HABITAT AND BEHAVIOR OF JUVENILE PACIFIC ROCKFISH
(SEBASTES SPP. AND SEBASTOLOBUS ALASCANUS) OFF SOUTHEASTERN
ALASKA

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ABSTRACT

Nursery grounds of Pacific ocean perch (Sebastes alutus) off Alaska must be located so that the feasibility of indexing their abundance before recruitment to the fishery can be assessed. Trawl catches of foreign fishing and U.S. research vessels on the fishing grounds have contained only a few older juveniles (4- to 5-yr olds) and no 1- to 3-yr-old Pacific ocean perch; however, small juveniles have been captured in a few coastal bays and fiords of southeastern Alaska. Biologists have hypothesized that the extremely uneven and virtually unsampled rocky bottom between 20 and 80 fathoms is the nursery grounds for this species. Because this area cannot be sampled by conventional fishing methods, we used the submersibles Nekton Gamma and Mermaid II to visually locate and sample juvenile rockfish and describe their habitat and behavior. Large compact schools and solitary small red rockfish (Scorpaenidae) were observed in 1978 and 1980. In 1983, five species of juvenile rockfish, including Pacific ocean perch, were captured, identified, and aged. Juvenile rockfish, particularly Pacific ocean perch and sharpchin rockfish (S. zacentrus), sought refuge in crevices between rocks and along the side of boulders when frightened. For this reason, juvenile rockfish are difficult to sample by conventional methods, even in areas with smooth bottom, which are amenable to trawling.

INTRODUCTION

During the 1960's and early 1970's, Pacific ocean perch (Sebastes alutus) made up most of the foreign groundfish catch in the eastern Gulf of Alaska; however, by 1979, catches of Pacific ocean perch had declined, and the stocks were considered to be overfished (Ito, 1982). The United States now prohibits foreign trawling in the eastern Gulf of Alaska east of 140°W longitude so that Pacific ocean perch stocks can rebuild and be profitably harvested by U.S. fishermen.

Eliminating foreign fishing in the eastern Gulf of Alaska also eliminated the main data base used by fishery managers to monitor stock abundance. As a result, the National Marine Fisheries Service now conducts triennial research trawl surveys in this region. Catches of Pacific ocean perch in these surveys have been mainly adults (6- to 8-yr-olds and older). Four- and five-year-old Pacific ocean perch are caught occasionally in catches of U.S. research vessels and foreign trawlers; 1-to 3-yr-olds are

not. Subsequently, any effect of prohibiting foreign fishing on the rebuilding of Pacific ocean perch stocks is not measurable until a year class enters the adult population at 6-8 yr.

If the location of nursery grounds for Pacific ocean perch were known and juveniles could be effectively sampled, trends in stock abundance could be measured several years before the year class is recruited to the fishery. Small juvenile Pacific ocean perch have been captured in a few coastal bays and fiords in southeastern Alaska over steep slopes and ledges near rocky areas (Carlson and Haight, 1976). The lack of juveniles in offshore catches and their occurrence in catches in coastal bays and fiords led these authors to hypothesize that the extremely uneven rocky bottom areas nearer the coast than the area occupied by the adults are nursery grounds for Pacific ocean perch. Juvenile demersal fish inhabiting these areas have not been extensively sampled because rugged bottom and strong tidal currents preclude deployment of conventional fishing gear (e.g., trawls, traps, gill nets).

In 1978, Carlson and Straty (1981) used the two-man submersible Nekton Gamma to visually search for young Pacific ocean perch in two rocky-bottom coastal areas and in an adjacent bay and strait protected from open-sea conditions in the northern part of southeastern Alaska. They observed large schools of "reddish rockfish" that they believed to be Pacific ocean perch; however, they were unable to verify the identification.

In an extension of Carlson and Straty's (1981) work, we used the submersibles Nekton Gamma and Mermaid II to locate, observe, and capture small juvenile red rockfish off the coast of southeastern Alaska in 1980 and 1983. The primary objectives of these surveys were to describe and photograph the habitat and behavior of juvenile rockfish and secure specimens of them for identification. Pacific ocean perch was the target of our investigations because of its former commercial abundance and potential value to U.S. fishermen. In this paper, I present our observations of the habitat and behavior of young rockfish of those species successfully captured and identified during the 1983 submersible survey and discuss some possible implications of this new information.

METHODS

Fourteen locations off the coast of southeastern Alaska between Cape Cross and Cape Muzon were surveyed with a submersible in 1980 (Fig. 1). Sixteen coastal locations in the same area were surveyed in 1983. The selected coastal sites had the type of habitat where Carlson and Straty (1981) observed large concentrations of small juvenile red rockfish. In addition, two bays on the east side near the southern tip of Baranof Island were surveyed in 1983. Juvenile Pacific ocean perch were captured by trawl in these bays by Carlson and Haight (1976). Depth of the survey sites ranged between 37 and 223 m. Sites with hard bottoms ranging from almost flat to extremely steep with frequent changes in relief (Fig. 2) were preferred.

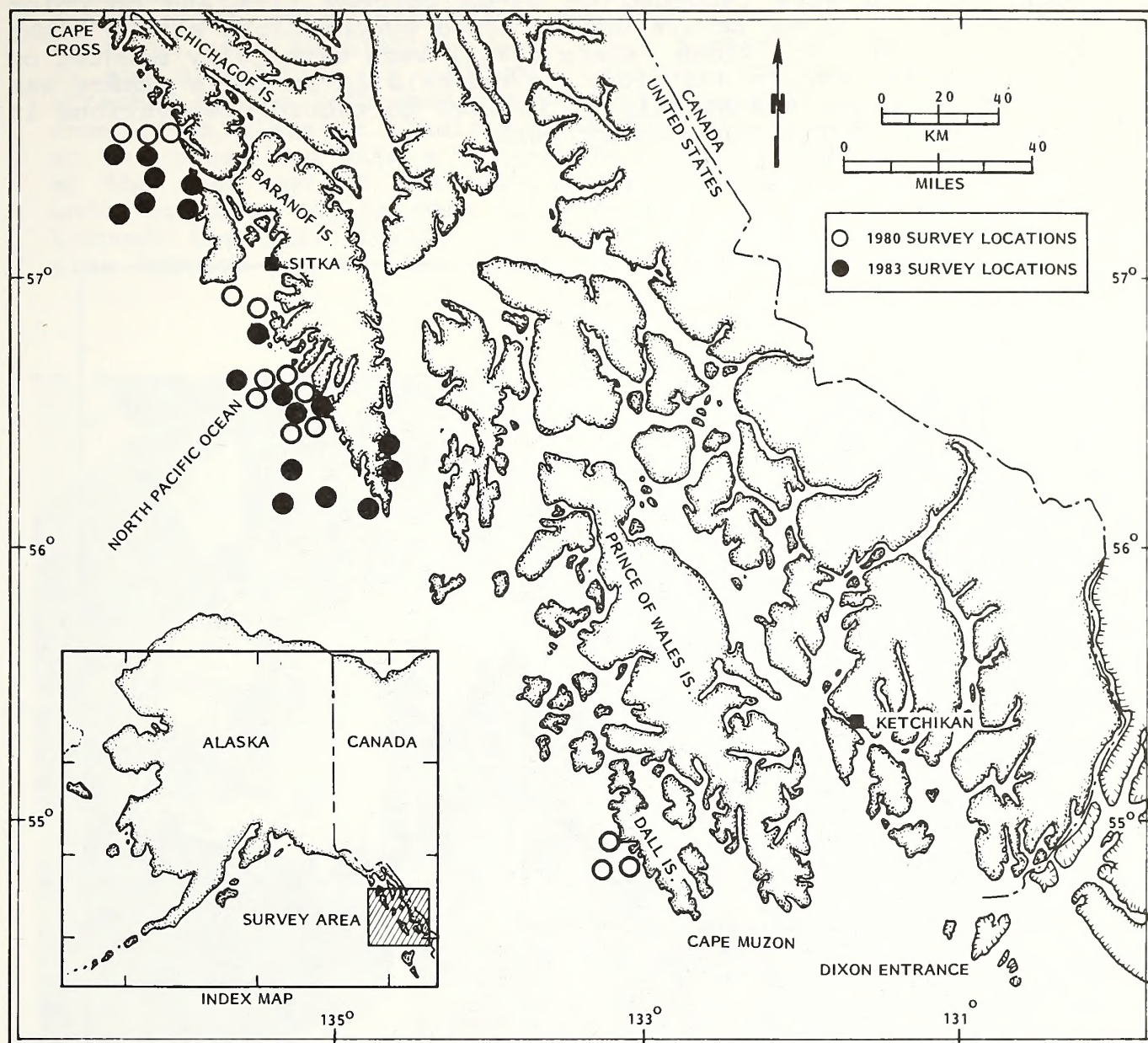


Figure 1. Location of submersible surveys for juvenile rockfish off southeastern Alaska, August 1980 and 1983.

Observations of juvenile rockfish behavior and habitat at each location were recorded on 35-mm colored film and on color video tape. A 35-mm camera and attached synchronized strobe light (1980 and 1983) and video camera (1983) were externally mounted on the submersibles. In addition, a hand-held 16-mm movie camera was used from inside the Mermaid II in 1983 to record observations in color taken through the forward port.

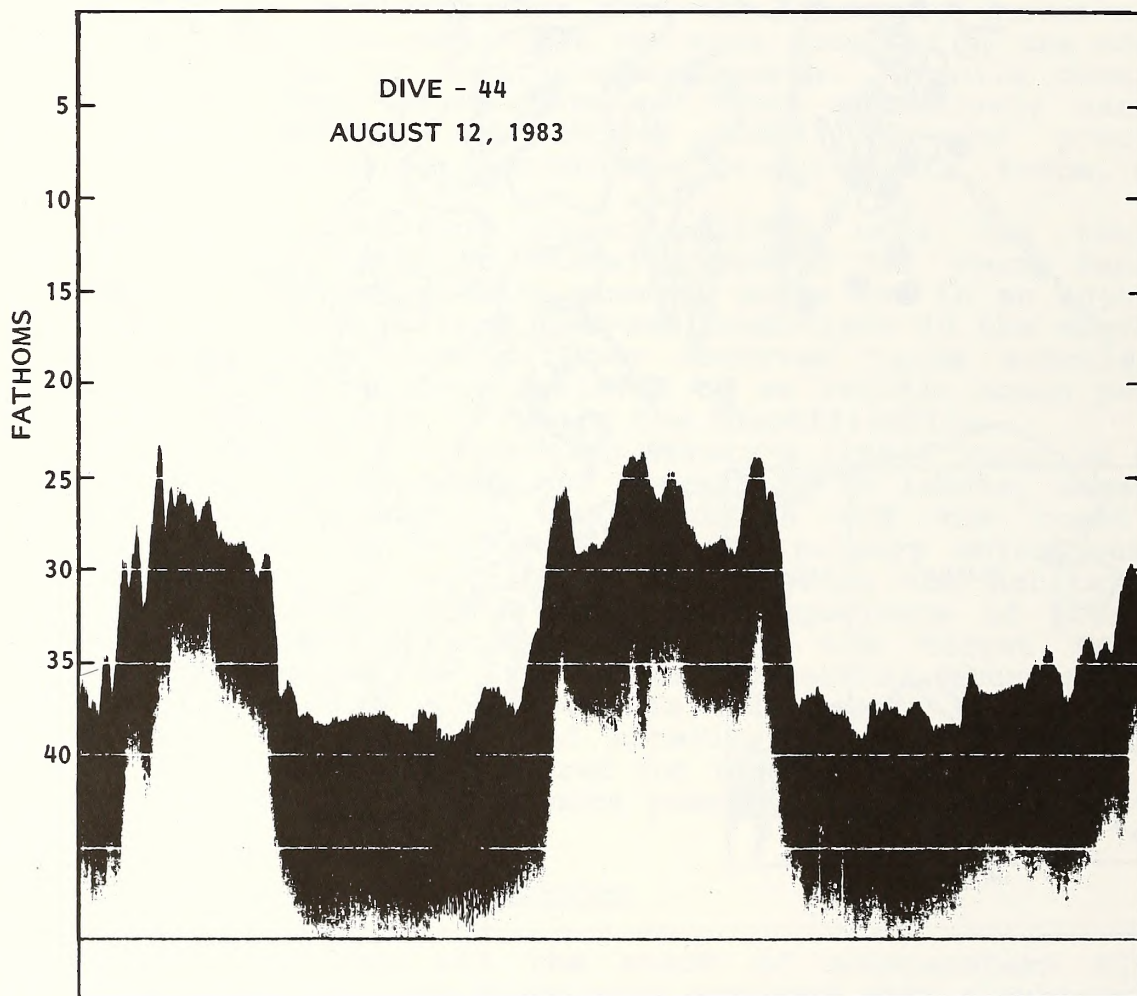


Figure 2. Typical bottom topography of areas surveyed for juvenile rockfish off southeastern Alaska, August 1980 and 1983.

In 1980, we unsuccessfully tried to collect small juvenile rockfish with baited minnow traps and small variable-mesh monofilament nylon gill nets deployed from the submersible. In 1983, we used an electric motor- and pump-driven slurp gun (Fig. 3) and a sedative to capture juvenile rockfish. The slurp gun, attached to the left manipulator of the Mermaid II, was fabricated from 13-cm diameter aluminum pipe open at one end and was fitted at the other end with a 0.64-cm mesh net collecting bag. Suction at the open end of the pipe was created when water was pumped under pressure (60 gal/min [227 l/min] at 80 lb/in.² [5.6 kg/cm²]) through the pipe toward the net bag. Water was pumped to the pipe through 2.5-cm plastic hose by a vane pump attached near the

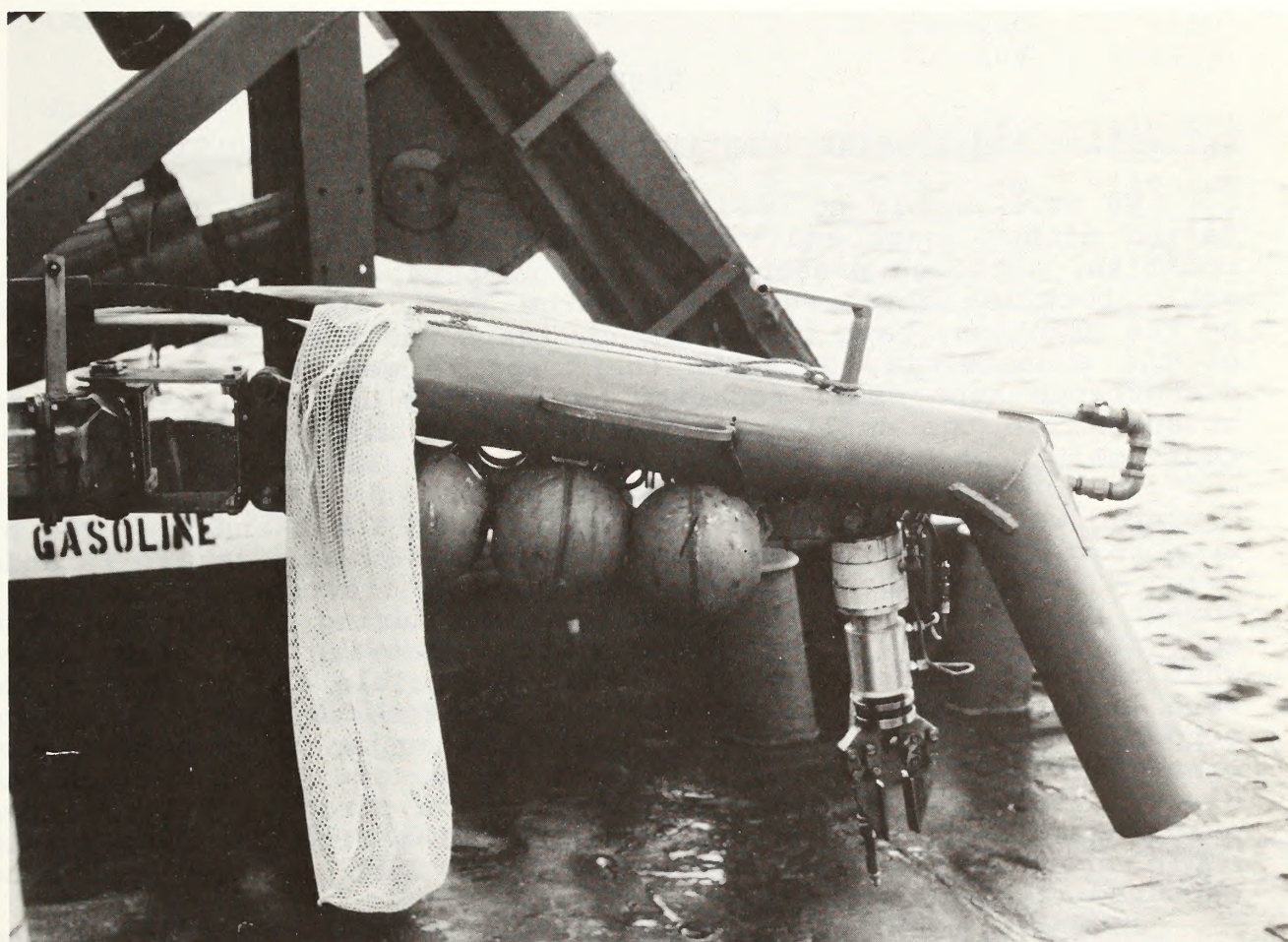


Figure 3. Slurp gun attached to the manipulator of submersible Mermaid II and used to capture juvenile rockfish off southeastern Alaska, August 1983.

stern of the submersible and driven by a 7-hp electric motor. When the batteries of the submersible were fully charged, the suction created at the open end of the slurp gun by this venturi design was sufficient to capture small (<60 mm in length) sedated fish at a distance of 30 cm. At closer distances, fish up to 20 cm could be captured. The sedative, quinaldine (2-methylquinoline), was placed in an air-charged scuba bottle and was dispensed into the water through a plastic hose connected to a nozzle attached to the same manipulator as the slurp gun. Quinaldine was premixed with ethyl alcohol to give a 20% quinaldine solution. Fish exposed to this concentration became sedated within 15-30 s; however, bottom currents and buoyancy of quinaldine solution made it difficult to expose fish for this time. In most instances, juvenile rockfish were collected with the slurp gun without the quinaldine solution.

RESULTS

Collection and species identification of juvenile rockfish

We were unable to collect juvenile rockfish in 1980 with the baited minnow traps and variable-mesh gill nets because juvenile rockfish, although present in large numbers, were driven off when adult rockfish appeared. These large fish, apparently attracted by the plankton, bait in the minnow traps and the noise and lights of the submersible, attacked the traps to get at the bait. This disturbance kept small rockfish away. Large rockfish also became entangled in the small-mesh gill nets and created a disturbance that again kept small rockfish away.

In 1983, 83 juvenile red rockfish of five species were captured with the slurp gun at 12 of the 16 locations surveyed by submersible off the outer coast of Baranof and Chichagof Islands (Fig. 1). These rockfish represent only a fraction of the total number of juvenile red rockfish observed during the surveys, and most are species that sought refuge between or near rocks when alarmed by the movement of the submersible and slurp gun. We were unable to capture juvenile red rockfish that were in large schools above the substrate, near the upper slopes of rocky pinnacles and over them (see Figs. 5, 6, 9, and 11 of Carlson and Straty, 1981). Some method of dispensing a directed jet of large quantities of quinaldine a distance of ≥ 1 m from the submersible could probably be used to sedate these fish so they could be captured with the slurp gun.

Juvenile rockfish collected in our studies were identified from counts of anal, pectoral, and soft dorsal fin rays, gill rakers, lateral-line scales or pores, scale rows below the lateral line, the presence or absence of an extra head spine, and the length of the second anal-fin spine. All juvenile rockfish were measured (standard and fork lengths), and the age of most species was determined from otoliths and scales (Table 1). Otolith ages were determined by the "break-and-burn" technique (Chilton and Beamish, 1982).

Table 1. Age, size and depth of occurrence of juvenile rockfish, Sebastes spp. and Sebastolobus sp., captured during submersible surveys off southeastern Alaska, 5-13 August, 1983. Ages of shortspine thornyheads were estimated from length-age relationships (P. Miller, NMFS Auke Bay Laboratory, pers. comm. 1984).

Species	Age in years	Number at each age	Range in fork length (mm)	Depth range of capture (m)
Pacific ocean perch, (<u>Sebastes alutus</u>)	1	1	78	146-149
	2	2	104-115	134
	3	2	151-164	146-171
Sharpchin rockfish, (<u>Sebastes zacentrus</u>)	1	12	44-75	116-171
	2	9	83-106	116-131
	3	4	141-170	134-149
	4	2	176-197	143-171
	5	2	205-206	171
Pygmy rockfish, (<u>Sebastes wilsoni</u>)	1	12	47-81	81-143
	2	14	81-120	81-143
	3	13	125-173	85-143
Puget Sound rockfish, (<u>Sebastes emphaeus</u>)	1	2	70-89	81
	2	1	121	81
Shortspine thornyhead, (<u>Sebastolobus alascanus</u>)	1	1	78	222
	3	1	110	171
	5	2	134-150	222
	7	1	174	171
	11	2	220-226	171-222
Unidentified <u>Sebastes</u> sp.	2	1	106	115

Juvenile Pacific ocean perch and sharpchin rockfish Sebastes zacentrus were captured at similar depths (Table 1) in similar habitat (Fig. 4). Both species have barred blotches on the back and upper lateral surfaces. This marking generally extends below the lateral line of juvenile sharpchin rockfish but not below the lateral line of juvenile Pacific ocean perch (Fig. 5). The consistency of this difference, however, cannot be determined without examination of many specimens collected from various parts of the range of the two species. If consistent, the difference in color pattern could be used to identify these species visually from a submersible and from photographs.

Juvenile pygmy rockfish, Sebastes wilsoni, which were more prevalent at shallower depths than juvenile Pacific ocean perch and sharpchin rockfish (Table 1), have less distinct blotches than sharpchin rockfish and Pacific ocean perch. Furthermore, pygmy rockfish have a reddish back and white belly, coloration sufficiently different from juvenile Pacific ocean perch and sharpchin rockfish to distinguish between these species from the submersible even though the identity of pygmy rockfish was not known when collected.



Figure 4. Juvenile Pacific ocean perch or sharpchin rockfish in typical habitat off southeastern Alaska, August, 1983.

One Puget Sound rockfish, Sebastes emphaeus, was positively identified and two were tentatively identified. Puget Sound rockfish were captured at the shallowest location surveyed (Table 1). Juvenile shortspine thornyheads, Sebastolobus alascanus, could be easily identified from the submersible (Fig. 6). They lack the barred blotches of juvenile Pacific ocean perch, sharpchin rockfish, and pygmy rockfish and have the distinctive shape and dark-orange uniform coloration of the adults.

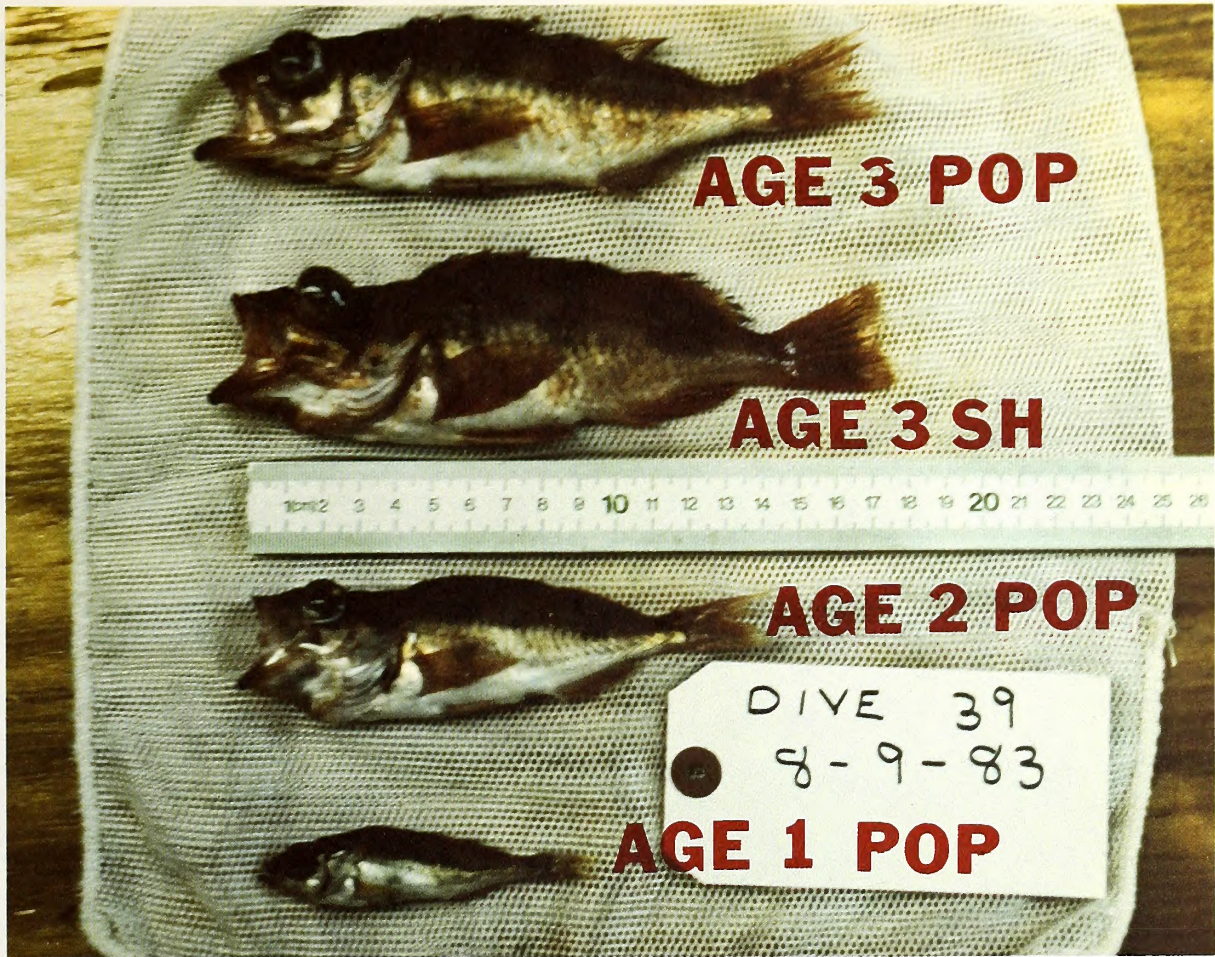


Figure 5. Three juvenile Pacific ocean perch (POP) age 1, 2, and 3 years and an age-3 sharpchin rockfish (SH) captured with a submersible slurp gun off southeastern Alaska, August 1983.

The color of the blotches on juvenile rockfish changed between the time they were captured with the slurp gun and the time they were later examined on the surface. The change was particularly noticeable in juvenile Pacific ocean perch and sharpchin rockfish. When observed from the submersible, the barred blotches on the back and upper lateral surfaces of these species appeared to be made up of alternating dark and almost white markings (Figs. 4, 7 and 8). When examined later on the surface, the white markings had changed to the reddish-orange of the rest of the body. This change was so striking, it was difficult to believe we were looking at the same fish we had collected.

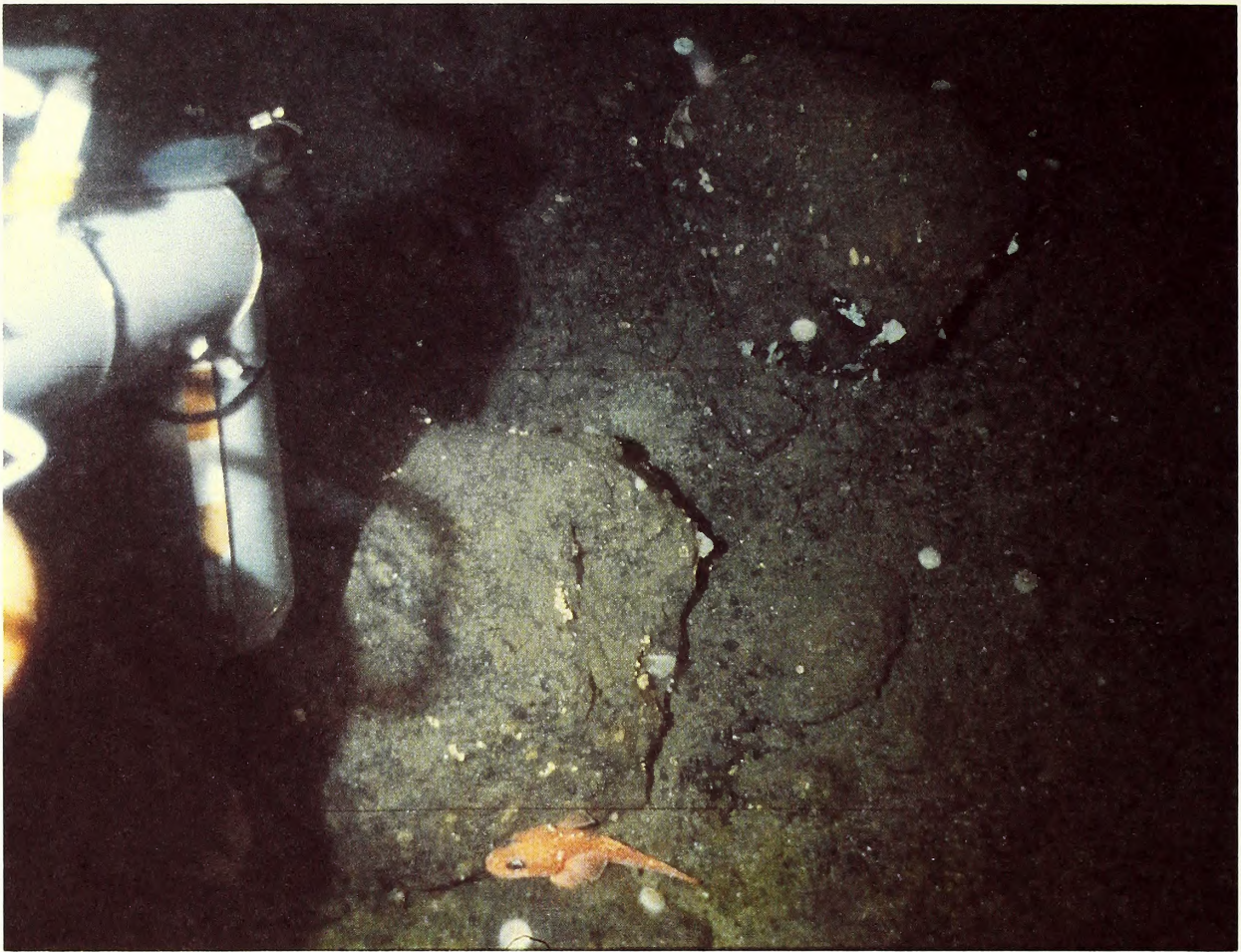


Figure 6. Juvenile shortspine thornyhead seeking refuge near a boulder off southeastern Alaska, August 1983.

The ability to change color quickly was observed in situ when an apparently alarmed juvenile red rockfish changed color on its back from a uniform to a barred blotched pattern. This observation was made at the shallowest depths surveyed (81 m) and would exclude Pacific ocean perch and sharpchin rockfish as the likely species observed.

Depth distribution and age of juvenile rockfish

With the exception of the shortspine thornyheads, most juvenile rockfish were 1- to 3-yr-old (Table 1). Larger, presumably older juvenile red rockfish with the coloration pattern of those captured were observed and photographed but were too elusive to be captured with the slurp gun. Too few juvenile



Figure 7. Juvenile Pacific ocean perch or sharpchin rockfish seeking refuge between boulders off southeastern Alaska, August 1983.



Figure 8. Juvenile Pacific ocean perch or sharpchin rockfish seeking refuge near a cobble off southeastern Alaska, August 1983.

rockfish of each species were collected to show a depth preference by age. Shortspine thornyheads had the deepest distribution, and the pygmy rockfish and Puget Sound rockfish had the shallowest distribution (Table 1). Pacific ocean perch and sharpchin rockfish had an intermediate and similar depth distribution.

Habitat and behavior of juvenile rockfish

The 1- to 3-yr-old Pacific ocean perch and 1- to 5-yr old sharpchin rockfish were observed and captured in similar habitat. Individuals or groups of two to three fish separated by 0.5-1.0 m or more were observed over bare to lightly silt-covered cobble (64-256 mm in diameter) interspersed with frequent boulders (256 mm and larger) (Figs. 4, 7, 8). The shallower habitat of 1- to 3-yr-old pygmy rockfish and Puget Sound rockfish was also bare or lightly silt-covered but contained more large boulders, boulder piles and solid rock outcrops. The habitat of 1- to 11-yr-old shortspine thornyheads captured at the deepest locations (Table 1) was bare to lightly silt-covered cobble (64-256 mm in diameter) with fewer large boulders than the habitats of other species of juvenile rockfish (Fig. 6) (shortspine thornyheads at Cape Ommaney mature between age 6 and 13; P. Miller, NMFS Auke Bay Laboratory, M.S. Thesis, in preparation). Individual or groups of two or three juvenile shortspine thornyheads separated by 0.5 m or more were captured in areas with few abrupt changes in bottom relief and no solid rock outcrops.

Juvenile red rockfish were observed in areas having stands of large white anemones, Metridium senile, on the upper slopes and tops of rock outcrops or pinnacles at depths ≤ 171 m (see Fig. 11 in Carlson and Straty, 1981). In 1983, we collected pygmy rockfish and Puget Sound rockfish from this type of habitat but no juvenile Pacific ocean perch, sharpchin rockfish, or shortspine thornyheads.

Small juvenile Pacific ocean perch, sharpchin rockfish, pygmy rockfish, and shortspine thornyheads sought refuge in the spaces between and along the side of cobbles and rocks when alarmed by movement of the submersible and slurp gun (Figs. 7 and 8). They placed one side against a cobble or boulder, assumed the curvature of the rock (Figs. 6 and 8), then ceased moving (species verification based on colored video tape recordings of captured fish, which were later identified). This behavior made these rockfish easier to capture with the slurp gun than continuously moving species in large schools 0.5-1 m or more above the substrate (see Figs. 5, 6, 9 and 11 of Carlson and Straty, 1981).

DISCUSSION

The barred blotches of 1- to 3-yr-old Pacific ocean perch and their behavior of remaining near or in frequent contact with the substrate casts doubt on speculation by Carlson and Straty (1981) that the "clouds of 6-8 cm reddish rockfish" they observed near and on the top of rocky pinnacles are juvenile Pacific ocean perch. We observed many similar schools of small reddish rockfish

in the same habitat during the 1980 and 1983 submersible surveys. In colored photographs taken of these schools in 1978, 1980, and 1983 during submersible surveys, the small rockfish either lacked the prominent barred blotches of juvenile Pacific ocean perch and sharpchin rockfish or the blotches were much less prominent. Photographs taken in 1978 at depths deeper than areas where these large schools were found had small rockfish with the prominent barred blotches characteristic of Pacific ocean perch and sharpchin rockfish, and the habitat was the same as the habitat where we found Pacific ocean perch and sharpchin rockfish in 1983.

Habitat of 1- to 3-yr-old Pacific ocean perch off the outer coast of southeastern Alaska recorded in the submersible surveys is markedly different from the habitat described and photographed for this species inside several adjacent coastal bays and fiords (Carlson and Haight, 1976): the substrate off the coast has less silt cover and many more cobbles and large boulders. The substrate inside coastal bays has many shell fragments, whereas none were observed in photographs and colored video recordings of the substrate at offshore locations.

Two of the bays surveyed with a bottom trawl by Carlson and Haight (1976), Big Port Walter and Port Conclusion, near the southern tip of Baranof Island (Fig. 1), were surveyed by submersible in 1983. We were unable to capture juvenile rockfish in these bays although some were observed that had the appearance of Pacific ocean perch or sharpchin rockfish. The fish were not nearly as abundant in these bays as at offshore locations possibly because of differences in substrate composition between offshore and bay locations. The cobble and boulders noted at offshore locations and resulting spaces between them probably offered more refuge than substrate inside bays.

Although more small juvenile rockfish were observed offshore than inside the bays, the offshore locations did not appear to have nearly as many fish as could be accommodated by the amount of refuge between boulders and cobbles. If available refuge is a factor limiting the abundance of small juvenile rockfish in an area, the offshore areas surveyed appeared to be underutilized and may reflect the present low abundance of Pacific ocean perch off southeastern Alaska.

Differences in the substrate composition between bays and offshore locations, the behavior of 1- to 3-yr-old Pacific ocean perch when alarmed, and the types of fishing gear used by commercial and research fishing vessels to capture adult and juvenile perch may explain why small juvenile Pacific ocean perch have only been previously captured inside bays and not offshore. Off the coast of southeastern Alaska, bottom trawls of foreign commercial fishing and U.S. research vessels are fitted with rubber rollers to keep the net off bottom and avoid snagging it on frequent large boulders. Trawls used by U.S. research vessels engaged in sampling groundfish off the coast of southeastern Alaska use 14-in. (36 cm) diameter rollers in the wings and 18-in. (46 cm) diameter rollers in the middle of the net (Fred Wathne, NMFS Laboratory, Seattle, Washington, pers. commun. 1984). The bottom of the trawl entrance is 7-9 in. (18-23 cm), off the

bottom. Foreign trawlers previously fishing for Pacific ocean perch off southeastern Alaska used larger nets and rollers than U.S. fishing vessels. The behavior of 1- to 3-yr-old Pacific ocean perch and other juvenile rockfish species when alarmed keeps them close to the bottom, well below the entrance to these trawls. Carlson and Haight (1976) did not use rubber rollers on trawls used to sample fish inside bays in 1976 (H.R. Carlson, NMFS Auke Bay Laboratory, pers. commun. 1984). The entrance of the trawl thus remained on a bottom that had fewer cobbles and boulders than the bottom offshore; thus, more small juvenile Pacific ocean perch could be captured. The trawls used by these authors also had smaller mesh, which retain more small fish than trawls fished offshore.

Because large juvenile and adult Pacific ocean perch, sharpchin rockfish, and shortspine thornyheads off the coast of southeastern Alaska are caught in trawls, these species probably venture farther above the bottom with increasing age and size, as our observations and photographs show. Larger juvenile rockfish in the same habitat as small juveniles would also be more vulnerable to capture by trawls with rollers than small juveniles.

Although adult Pacific ocean perch form schools (see Major and Shippen, 1970), 1- to 3-yr-old Pacific ocean perch apparently do not form schools as Carlson and Haight implied (1976). Individual or loose aggregations of juveniles were observed in close contact with the bottom and separated by ≥ 0.5 m, rather than in schools. Pacific ocean perch and probably sharpchin rockfish and other Sebastes spp. whose juveniles have a distribution similar to Pacific ocean perch probably form larger, more compact schools with increasing age and size.

Although only a few of each species of 1- to 3-yr-old juvenile rockfish were captured during submersible surveys, many more of the same size, coloration, and behavior, and in the same or similar habitats were observed and documented on colored, video tape and 35-mm film. This type of information could have only been obtained with a manned, maneuverable underwater vehicle in regions like those off the coast of southeastern Alaska. Although the offshore areas appear to be more important than bays as nursery grounds for 1- to 3-yr-old Pacific ocean perch and other rockfish species, it is unlikely that offshore areas can be effectively and economically sampled by present fishing techniques. Trawl sampling of these age groups in coastal bays over smoother bottom may provide the only effective means of measuring trends in the abundance of Pacific ocean perch during the early juvenile stage of their life history.

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LEVELS OF HEAVY METALS, POLYCHLORINATED
AND POLYBROMINATED BIPHENYLS IN THE
FAIR AND THE NEW ENGLAND

Northwest Passage, 1967

William F. Foltz

2. West 10th St.

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CHAPTER III

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LEVELS OF HEAVY METALS, PETROGENIC HYDROCARBONS,
AND POLYCHLORINATED BIPHENYLS IN SELECTED MARINE SAMPLES
FROM THE NEW ENGLAND COAST

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ABSTRACT

The levels of seven heavy metals (Ba, Cr, Cd, Pb, Hg, Zn), petrogenic hydrocarbons, and polychlorinated biphenyls were determined for two marine algae, eight marine animals, and sediment collected in situ during 1980 and 1981. Faunal samples were taken of prominent endemic species at eight sites. Collection areas were: Northern New England coast, Southern New England coast, Georges Bank, and Georges Bank submarine canyons.

This report presents the results from sample analyses. Levels of metals were within expected ranges, although particular organs or particular specimens seemed to concentrate certain metals. Petrogenic hydrocarbons and polychlorinated biphenyls were at very low levels or nonexistent.

INTRODUCTION

A program to monitor the health of the coastal marine environment, namely the Northeast Monitoring Program (NEMP), was established by the National Marine Fisheries Service (NMFS) in 1978. This program is a multifaceted approach, using a variety of scientific disciplines, to assess the extent to which our marine environment has been or may be affected by pollution. As part of this program the Manned Undersea Research and Technology (MURT) program of the Northeast Fisheries Center (NEFC) began a research project in 1978 using in situ diving techniques to determine benchmark population densities of selected species and pollutant body burdens of dominant macrobenthic species at sites along the New England coast, on Georges Bank and offshore submarine canyons (Figure 1). The MURT sites are complementary to the overall NEMP coverage and represent areas difficult to sample with conventional surface techniques. Nearshore areas are hard bottom substrates with attached flora and fauna that can be most effectively studied and collected by divers. The offshore study sites are biologically rich canyons with ocean floor fauna and substrates most accurately censused by manned submersibles. This paper will present the levels of heavy metals (barium, cadmium, copper, chromium, lead, mercury, zinc), petrogenic hydrocarbons, and polychlorinated biphenyls found in our array of samples.

The three general areas selected for study were: 1) Jeffreys Ledge, Gulf of Maine, 2) Block Island, Rhode Island Sound, and 3) Georges Bank and adjacent Lydonia and Oceanographer submarine canyons. Each represents a different and distinct marine environment. The locations and depth of each station is presented in Table 1. Samples for analysis were collected from Jeffreys Ledge and Block Island in 1980 and from the remaining

sites in 1980 and 1981.

Pigeon Hill at Jeffreys Ledge in the Gulf of Maine was selected for its pristine nature, accessibility by scuba, and background of study. The biology and geology of Jeffreys Ledge has been a subject of study by us and other scientists since 1971. Surveys of herring spawning areas there have been discussed by Cooper et al. (1975), the biology and geology by McCarthy et al. (1979), Sears and Cooper (1978), Witman et al. (1980), Pecci and Hulbert (1981a, 1981b), Hulbert et al. (1982), and Witman and Cooper (1983). This hard bottom undersea knoll at a depth of 33 meters has a complex community of flora and fauna typical of boreal benthic communities north of Cape Cod, and because of its isolation the benthic community is relatively unimpacted by pollution sources. Three dominant species representing different trophic levels were selected from this site for analysis: red algae (*Ptilota serrata*), ascidians (*Ascidia callosa*), and sea stars (*Henricia sanguinolenta*).

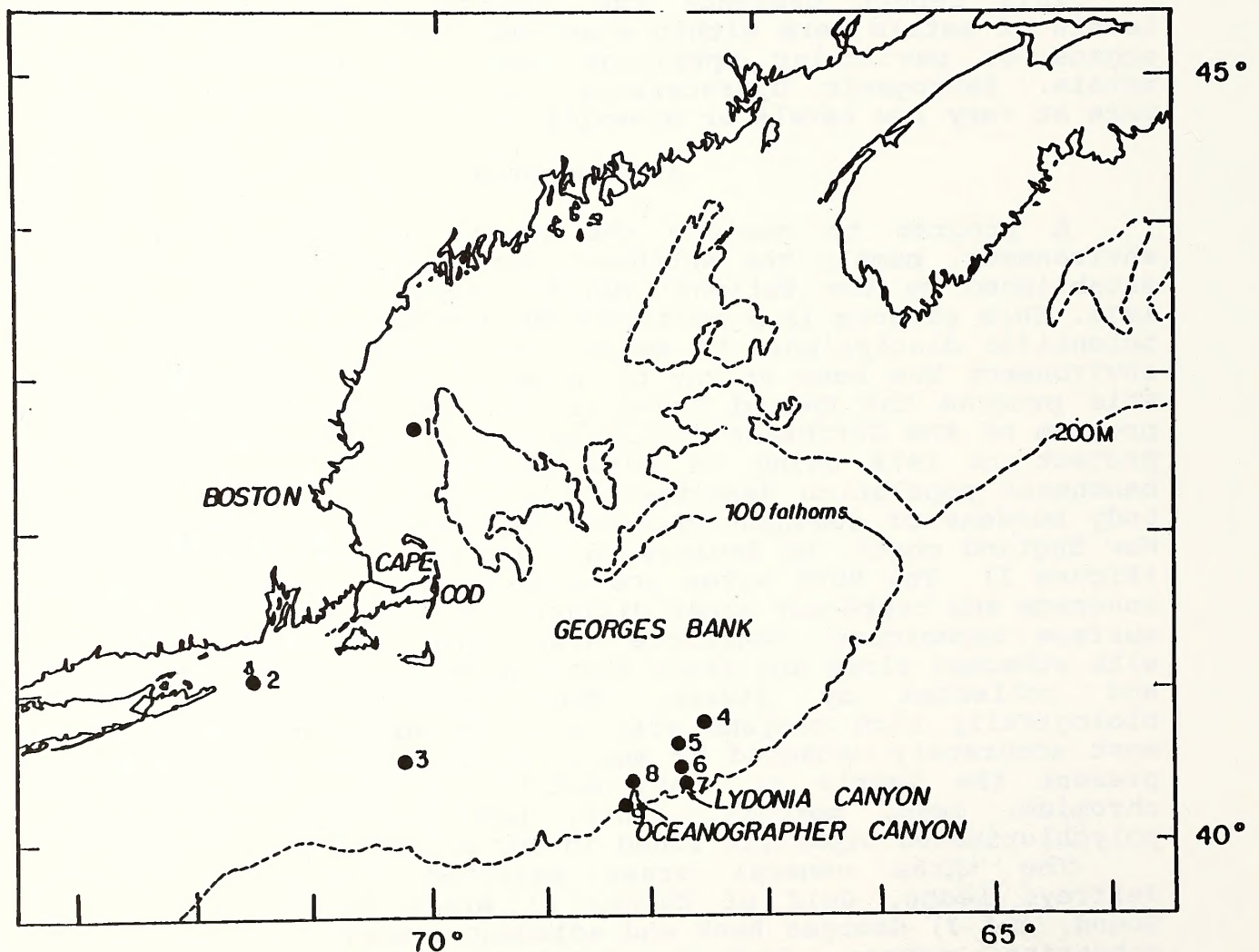


Figure 1. Location of collection sites of samples for pollutant analysis.

Table 1. Location and depth of sampling sites for contaminant analysis.

Station Number	Location	Depth (fathoms)
1	Jeffreys Ledge 42° 46.5'N 70° 14.5'W	18
2	Block Island 41° 07.7'N 71° 34.2'W	11
3	Mud Patch 40° 29.7'N 70° 12.2'W	50
4	Georges Bank 40° 42.5'N 67° 27.5'W	47
5	Georges Bank 40° 37.2'N 67° 44.7'W	42
6	Lydonia Canyon 40° 32.2'N 67° 42.5'W	75
7	Lydonia Canyon 40° 27.6'N 67° 41.5'W	97
8	Oceanographer Canyon 40° 29.6'N 68° 09.2'W	100
9	Oceanographer Canyon 40° 25.5'N 68° 09.2'W	130

The second inshore area we sampled was off Block Island, Rhode Island Sound. This collection site is a boulder mount rising from a sand ocean floor at 20 meters to within 8 meters of the surface. This topographically irregular rocky area supports a biological assemblage dominated by red algae (Phycodrys rubens), anemones (Metridium dianthus), and sea stars (Asterias vulgaris) (Pecci and Hulbert, 1982). These three species were collected for pollutant analysis. The Block Island site is impacted by nearby population and industrial centers, thus the potential for increased effects from human and industrial wastes.

Our third general area of study is the outer continental shelf, including oil lease tracts, nearby submarine canyons, and the "mud patch", an area of reduced current and sedimentation. Sampling was conducted at seven sites, two each at Oceanographer and Lydonia submarine canyons, one in the mud patch, and two on Georges Bank. These stations are located in areas which support a prolific commercial fishery. Amidst this fishing area, tracts of ocean bottom have been leased for exploration of oil and gas, posing some potential for environmental impact from the drilling activity itself or from the loss of organic compounds. A background of submersible research on the geology and biology has been done by Valentine et al. (1980), Cooper and Uzmann (1982) and Cooper et al. (1983). At each sampling site we selected endemic species for benchmark evaluations of pollutant body burdens. The selected samples vary by station but encompass the American lobster (Homarus americanus), Jonah crab (Cancer borealis), tilefish (Lopholatilus chamaeleonticeps), sea scallop (Placopecten magellanicus), and surficial sediment.

These offshore sites vary topographically as well as biologically. Station 3, known as the mud patch, is in an area of reduced current movement resulting in a settling area for particulate matter from the Georges Bank gyre. Stations 4 and 5 are on tracts leased for petroleum exploration. Stations 6, 7, and 8 are located downstream from lease tracts and are within the heads of major submarine canyons. The canyon areas have a background of research effort, are important commercial fishing areas, and the canyons themselves act as conduits of waterborne material moving seaward from adjacent shelf areas (Valentine et al., 1980).

MATERIALS AND METHODS

Fish, invertebrates, algae, and sediment were collected for examination during this study. Sample type and collection method varied by study site and specimen, while sample preservation, preparation for analysis, and analytical technique were consistent by sample and by year.

Collection of specimens from the two inshore sites (Pigeon Hill and Block Island) were made in situ by scuba divers concurrent with other studies. Samples were collected from Jeffreys Ledge (Pigeon Hill) in July, 1980, and from Block Island in June, 1981, by divers detaching material from bedrock and placing it in appropriate containers. Upon return to the surface collected material was frozen until analysis time.

Collections of offshore samples from the Georges Bank, canyon, and mud patch areas were made during July of 1980 and 1981 concurrent with a manned submersible (JOHNSON-SEA-LINK) photographic survey. Collection techniques for the offshore samples were as follows: lobster and crabs were trapped at each site by use of standard commercial traps. Adult specimens of both species were used for analysis. Adult tilefish (60-100 cm total length) were procured by hook and line from the research vessel R/V JOHNSON and immediately frozen whole. Adult scallop and sediment samples were collected using the hydraulic arm of the submersible. They were placed in external containers for return to the surface where they were transferred to appropriate containers and frozen until analysis time.

Chemical analysis of our samples was done by Cambridge Analytical Associates of Watertown, Massachusetts. A minimum of 100 grams of material for analysis (wet weight) was delivered to them in a frozen condition. Dissections of lobster, crab, scallop, and tilefish were done to procure the desired flesh for study. Crab tissue was a composite of seven to ten individuals, with flesh from walking legs and pincer claws combined for an edible meat sample and, hepatopancreas combined for an internal organ sample. Lobster tissue (edible portion of chelipeds and abdomen combined) was a composite of ten specimens; the lobster egg sample was the combined eggs from seven berried females. Flesh from each tilefish was dissected from the right dorsal musculature just posterior to the head, excluding skin and scales. The remaining samples (algae, tunicates, sea stars, sediment) were subsamples from about 100 grams of composited material.

Analysis for heavy metals was performed by flame atomic absorption, furnace absorption, or manual cold vapor. Organic components of samples were detected by gas chromatograph with a flame ionization detector. Protocols were taken from the EPA document, Methods for the Chemical Analysis of Water and Waste (EPA 600 479-200). Analysis of samples was generally completed within six weeks of delivery.

RESULTS AND DISCUSSION

Heavy Metals

The concentration of metals (ppm wet weight) found in our samples is presented in Tables 2, 3, 4, and 5, with each table representing a collection location (Jeffreys Ledge, Block Island, and offshore) and year. Samples from Pigeon Hill were collected in 1980 and from Block Island in 1981. Those from offshore were collected from five sites in 1980 and six in 1981.

Inshore

The prominent benthic species collected from Pigeon Hill were sea stars, tunicates, and algae. The results of their analyses for heavy metals are presented in Table 2. Of the two animals analyzed, sea stars were consistently higher in metal content (with the exception of zinc) than ascidians. This relative elevation of metal levels may be due to a magnification associated with a higher trophic level of sea stars.

Table 2. Heavy metal concentrations found in samples from Pigeon Hill, Jeffreys Ledge, 1980.

Species	Metal Concentration (ppm wet weight)						
	Ba	Cd	Cu	Cr	Hg	Pb	Zn
Sea star (<u>Henricia sanguinolenta</u>)	48.1	1.04	1.84	0.9	0.034	0.46	11.1
Algae (<u>Ptilota serrata</u>)	46.4	0.04	1.77	2.3	0.027	1.31	16.2
Tunicates (<u>Ascidia callosa</u>)	29.1	0.06	0.76	0.7	0.009	0.18	34.2

The results of the analysis of Block Island samples (sea stars, algae, and anemones) is presented in Table 3. Again, sea stars contained higher levels of most metals. An exception was the elevated concentration of lead found in the red algae

Phycodrys, which may have been due to analytical error or contamination by a lead fishing sinker nearby at sampling time. The anemone Metridium had lower levels of all metals.

Samples at Block Island were chosen because of their numerical importance in the benthic community and also for their similarity to those collected at Pigeon Hill. Algae from both sites are small, erect, red forms growing on horizontal oriented hard substrate. Anemones and ascidians attach to hard bottom substrate and feed on suspended material. Sea stars collected for analysis are predatory and represent a higher trophic level. The trophic equivalence of species between the two inshore sites gives an opportunity for closer comparison between sites.

Barium levels were apparently elevated at both inshore sites. The apparent reason for this will be discussed later.

Offshore

Samples were collected from offshore in both 1980 and 1981 with five sites sampled in 1980 and six in 1981. Four stations were common to both years.

In 1980 samples of tilefish (station 7), Jonah crab (stations, 3, 4, 5, 6, and 7), American lobster (station 7), sea scallop (stations 4 and 5), and surficial sediment (stations 4, 5, and 6) were collected for analysis (Table 4). Edible flesh and viscera of crab, scallop, and lobster were tested; only edible musculature of tilefish was analyzed. In addition, newly extruded eggs from lobsters captured at station 7 were tested.

Table 3. Heavy metal concentrations found in samples from Block Island, Rhode Island, 1981.

Species	Metal Concentration (ppm wet weight)						
	Ba	Cd	Cu	Cr	Hg	Pb	Zn
Sea stars (<u>Asterias</u> <u>vulgaris</u>)	22.7	0.86	4.1	1.0	0.01	9.4	51.1
Algae (<u>Phycodrys</u> <u>rubens</u>)	123.9	0.34	1.65	0.6	0.006	78.6	15.2
Anemones (<u>Metridium</u> <u>senile</u>)	1.9	0.08	0.61	ND*	0.01	ND*	13.1

* ND = None detectable.

Jonah crabs were common to all sampling stations and their metal levels in edible flesh were similar between stations. A composite sample of crab hepatopancreas from station 7 was tested to determine metal levels in an internal organ. The hepatopancreas had elevated levels of all metals when compared to edible flesh, generally an order of magnitude higher, except for

zinc which was similar in concentration to that found in musculature. Zinc levels were higher for crab edible flesh than in other species. Also at station 7, lobsters were collected and their metal concentration in musculature was similar to crab with the exception of lobster having elevated levels of mercury (0.244 vs. 0.006 ppm). Concentrations of metals in lobster hepatopancreas were generally not elevated above muscle tissue with the exception of lead and cadmium (0.62 vs. 0.05 and 19.5 vs. 0.18, respectively). The eggs from berried lobsters at station 7 had similar levels of metals as flesh, with the exception of mercury (lower) and copper (higher), both by a factor of ten. Both the edible adductor muscle and viscera from sea scallops were analyzed from stations 4 and 5. Variability is evident but, note that scallop viscera had elevated levels of cadmium. Tilefish musculature had metal levels within the range of that found in other flesh with the exception being pronounced lower levels of cadmium, generally by a factor of 100. Our final samples during 1980 were sediment from stations 4, 5, and 6. In general, when sediment is compared to living tissue, barium and chromium were higher, copper was lower, and other metals were similar.

In the following year (1981) and the same month (July) a second round of sampling was completed at six offshore locations. There were four stations common to both years (4, 5, 6, and 7); stations 8 and 9 at Oceanographer were new to the study and station 3 was omitted. Again Jonah crabs were common to all stations; lobsters were sampled at stations 7, 8, and 9; scallops at 4 and 5; tilefish at 6; and surficial sediment at 4, 5, 6, 8, and 9 (Table 5).

As in 1980, crabs had similar metal levels between stations and again zinc levels were elevated when compared to that in other flesh samples. Lobster samples of edible flesh had metal levels in agreement with those of crab, including mercury. Crab values for mercury were low in 1980 compared to lobster, but were similar in the following year. This may be due to natural variability or a sampling artifact. Sea scallops again had high levels of cadmium in comparison to other samples, although viscera had the most pronounced elevation (29.65 and 21.75 for viscera vs. 7.56 and 1.54 ppm for adductor muscle). Tilefish flesh had low levels of cadmium (0.002 ppm), zinc (4.75 ppm), and copper (0.45 ppm) when compared to the other samples. Sediment samples had higher barium, higher chromium, higher lead, and lower zinc concentrations than the living tissue samples.

Hall et.al. (1978) determined trace element levels in tissue of a wide variety of commercial marine species from the American coast. Included were rock crab (Cancer irroratus), American lobster (Homarus americanus), tilefish (Lopholatilus chamaeleonticeps), and sea scallop (Placopecten magellanicus). The areas of collection and muscle tissue used for analysis are in agreement with our methods and location. A comparison of metal levels between reports shows all in relatively close agreement with the exception of lead. Hall et al. consistently found lead levels an order of magnitude higher than our data.

Table 4. Metal concentrations in offshore samples collected in 1980. Values in ppm wet weight (ND = non detectable).

Station	Metal	PISCES	MOLLUSCA	
		Tilefish musculature	Sea Scallops adductor	viscera
3	Barium			
4			0.17	0.59
5			0.12	0.16
6				
7		0.21		
3	Cadmium			
4			4.92	77.0
5			0.50	41.7
6				
7		0.0002		
3	Copper			
4			0.25	22.2
5			1.30	2.52
6				
7		1.79		
3	Chromium			
4			0.53	0.60
5			0.39	0.24
6				
7		0.09		
3	Mercury			
4			0.222	0.019
5			0.014	0.013
6				
7		0.19		
3	Lead			
4			0.04	0.38
5			1.174	0.277
6				
7		0.90		
3	Zinc			
4			11.3	12.9
5			13.7	24.2
6				
7		3.7		

Table 4. (cont.) Metal concentration in offshore samples collected in 1980. Values in ppm wet weight (ND = none detectable).

CRUSTACEA								
Station	Metal	Jonah crab		American lobster				Sedi- ments
		leg	hepato- pancreas	claw	tail	pancreas	eggs	
3	Barium	0.14						
4		0.11						40.3
5		0.13						39.4
6		0.08						58.9
7		0.06	0.50	0.07	0.12	0.04	0.23	
3	Cadmium	0.14						
4		0.49						0.02
5		0.50						0.01
6		0.33						0.07
7		1.18	17.3	0.18	0.12	19.5	0.13	
3	Copper	9.8						
4		11.8						1.03
5		10.9						0.25
6		7.7						2.15
7		9.7	40.8	7.38	10.6	18.3	62.0	
3	Chromium	0.98						
4		0.18						3.1
5		0.22						3.8
6		0.47						11.3
7		0.07	0.92	0.05	0.06	0.07	0.24	
3	Mercury	0.034						
4		0.063						ND
5		0.050						ND
6		0.011						ND
7		0.006	0.064	0.218	0.270	0.087	0.035	
3	Lead	0.05						
4		0.94						0.40
5		0.08						0.38
6		0.06						0.52
7		0.78	0.23	0.05	0.07	0.62	0.07	
3	Zinc	95.6						
4		102.6						40.5
5		84.8						1.6
6		77.0						13.6
7		87.1	56.5	37.0	25.9	37.3	39.8	

Table 5. Metal concentration in offshore samples collected in 1981. Values in ppm wet weight. (ND = non detectable, replicate sediment samples taken at Stations 8 and 9).

Station	Metal	PISCES	MOLLUSCA	
		Tilefish musculature	Sea Scallops adductor	viscera
4	Barium		0.39	0.10
5			0.21	0.16
6		0.18		
7				
8				
9				
4	Cadmium		7.56	29.65
5			1.54	21.75
6		0.002		
7				
8				
9				
4	Copper		10.10	12.06
5			8.93	17.48
6		0.45		
7				
8				
9				
4	Chromium		0.20	1.15
5			0.02	0.66
6		ND		
7				
8				
9				
4	Mercury		0.40	0.10
5			0.27	0.22
6		0.29		
7				
8				
9				
4	Lead		0.06	0.06
5			0.42	0.09
6		0.06		
7				
8				
9				
4	Zinc		9.14	11.97
5			23.62	13.11
6		4.75		
7				
8				
9				

Table 5 (cont.) Metal concentrations in offshore samples collected in 1981. Values in ppm wet weight. (ND = none detectable, replicate sediment samples taken at Stations 8 and 9).

CRUSTACEA						
Station	Metal	Jonah crab	American lobster		Sediment	
		leg muscle	claw	tail muscle		
4	Barium	0.12				8.08
5		0.25				3.15
6		0.04				8.27
7		0.09	0.18			
8		0.17	0.06		7.32,	23.60
9		0.13	0.14		9.34,	6.81
4	Cadmium	0.26				0.19
5		0.03				0.12
6		0.07				0.24
7		0.05	0.01	0.01		
8		0.12	0.03	0.03	0.15,	0.32
9		0.13	0.11	0.11	0.15,	0.32
4	Copper	14.70				1.08
5		16.25				0.62
6		15.18				1.57
7		15.95	22.82	22.82		
8		14.42	5.02	5.02	0.75,	0.71
9		12.24	28.22	28.22	2.16	0.85
4	Chromium	0.04				4.23
5		0.04				5.06
6		0.16				7.28
7		ND		0.02		
8		ND		0.02	5.84,	3.16
9		0.08		0.17	11.00,	4.81
4	Mercury	0.88				0.34
5		0.95				0.23
6		0.51				0.40
7		0.33		0.27		
8		0.89		0.57	0.45,	0.95
9		0.59		0.87	0.08,	0.59
4	Lead	0.18				5.77
5		0.04				2.72
6		0.14				4.33
7		0.02	0.15			
8		0.12	0.05		3.39,	3.56
9		0.06	0.04		5.41,	4.62
4	Zinc	66.44				9.12
5		69.17				3.25
6		73.68				10.94
7		63.92	19.05			
8		89.29	23.23		5.09,	2.49
9		62.65	18.70		12.32,	3.54

Hydrocarbons

Many of the samples contained straight chain hydrocarbons, but the presence of interfacing biogenic hydrocarbons (fatty acids, etc.) made it impossible to identify petroleum contamination at such low levels. The flame ionization detector detects not only hydrocarbons but also the fatty acid makeup of the sample.

Straight chain hydrocarbons typically showed a series of dominant peaks at retention times between 25 and 38 minutes. This series of peaks accounted for 40-80 percent of the total peak areas in the samples, whereas, in the Crude Oil Standard it accounted for only 9 percent of the total peak area. There were no straight chain hydrocarbons detected in any of the sediment samples, nor was the 25-38 minute series of peaks detected. This suggests that these compounds are of biogenic origin and not from a petroleum source.

Aromatic hydrocarbons did not show a crude oil pattern. The lobster egg samples did not appear to contain aromatic hydrocarbons, but biogenic olefins which also appear, make the determination of trace amounts of aromatics very difficult. Aromatics were dominated by a group of three peaks at retention times between 20 and 24 minutes. These peaks accounted for 3-90 percent of the total peak area for different samples. There was also a predominant peak at a retention time of 29-30 minutes with an area percent between 3 and 82. These peaks were not present in aromatic fractions of the Crude Oil Standard, therefore they are not from a petroleum input.

Polychlorinated Biphenyls

All samples submitted in 1980 were tested for PCB content by gas chromatography. No polychlorinated biphenyls were detected in the sediment samples. However, in crab muscle, lobster tail, and tilefish, trace levels (20 ppb) were found which may be due to the presence of interfering compounds of biological origin. Because of the questionable presence of PCB's we assume they were not present or were present at very low levels.

Boehm (1978) found PCB's in scallop (1), rock crab (1), and American lobster (2) from samples collected during a survey for organic pollutants from Cape Hatteras to the Gulf of Maine. The crab was collected near the Delaware coast, the scallop and one lobster near the continental shelf off New Jersey and the other lobster south of Block Island, Rhode Island. The PCB levels he found (converted to a wet weight ratio by assuming an 85% weight loss during dessication), in the scallop, crab, and two lobsters were 0.0001, 0.0065, 0.225, and 0.0143 ppm, respectively.

CONCLUSION

The samples collected were for determination of metal and organic compound concentrations in localized species. The ambient levels found of metals were within the range anticipated. An exception was the high barium values found in Pigeon Hill, Block Island, and offshore sediment samples, which were disproportionally high. The apparent reason for this was a

complicating effect of calcium present in these samples. Small calcareous worm tubes were attached externally on both algae and tunicates and calcium compounds are present in sea stars resulting in an overestimation of barium. Consequently, these abnormally high values should be viewed with some skepticism. Petrogenic hydrocarbons and PCB's were at low or nonexistent levels.

The flesh or organs of some species seem to accumulate specific metals at a high level (Table 6). The association of these metals with specific tissues may offer a "watchdog" relationship for checking a selected tissue to follow a particular ambient metal level.

Table 6. Potential sentinel body portions for metal contamination monitoring at Georges Bank and offshore canyon areas.

Sample	Metals with elevated levels
Crab muscle	Zn
Crab hepatopancreas	Ba, Cd, Cu
Lobster hepatopancreas	Cd
Lobster eggs	Cu
Scallop adductor muscle	Cd
Scallop viscera	Ba, Cd, Cr

Compounds of petrogenic origin were not present in any appreciable level in our samples. Although interfering biogenic organic compounds complicated sample analysis, there was no apparent petrogenic contamination at sampling times. Also, PCB's were extremely low or nonexistent in our samples. Anthropomorphic contamination of our samples was minimal.

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STUDIES OF THE WATER COLUMN, SEDIMENTS, AND BIOTA AT THE
NEW YORK BIGHT ACID WASTE DUMPSITE AND A CONTROL AREA

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ABSTRACT

In situ studies of the New York Bight acid waste disposal site and a control site on the Cholera Bank 10 km to the north-northeast were carried out in August, 1982. Visual observations, sediment samples for infaunal analyses, and color videotape were taken to determine if there were differences between the two sites. Visual observations revealed no obvious differences in the condition of the animals at each site, and only minor differences in abundance. Core samples from the disposal site had slightly lower species diversity and numbers of polychaetes and crustaceans than did control samples. The water column and sediments at the disposal site were quite different from those at the control area in that the dumpsite had high concentrations of floc and aggregates of this floc. No material of this kind was observed at the control site.

INTRODUCTION

The New York Bight acid waste disposal site, located approximately 28 km due east of Long Branch, NJ (Figure 1), received for 33 years (1950-1982) the by-product from the manufacture of titanium dioxide at a rate of up to 2 million wet tons per year. The principal component of this waste is sulfuric acid, containing ferrous sulfate, residual ilmenite ore and some titanium dioxide, which when dumped, created a ferrous hydroxide flocculate which colors the water yellowish-green (Birmingham, 1982).

The dumpsite, known locally as the acid stain, has been in the past an area frequented by sport fishermen. Environmental groups have campaigned to have the dumping ended, claiming environmental degradation due to the dumped acid waste material. The U.S. Environmental Protection Agency (EPA) at the same time made a decision to permit the continuation of this dumping, based in part on NOAA data. Most acid waste disposal ended in 1982 when National Lead Industries, the major dumper, closed its Sayreville, NJ plant.

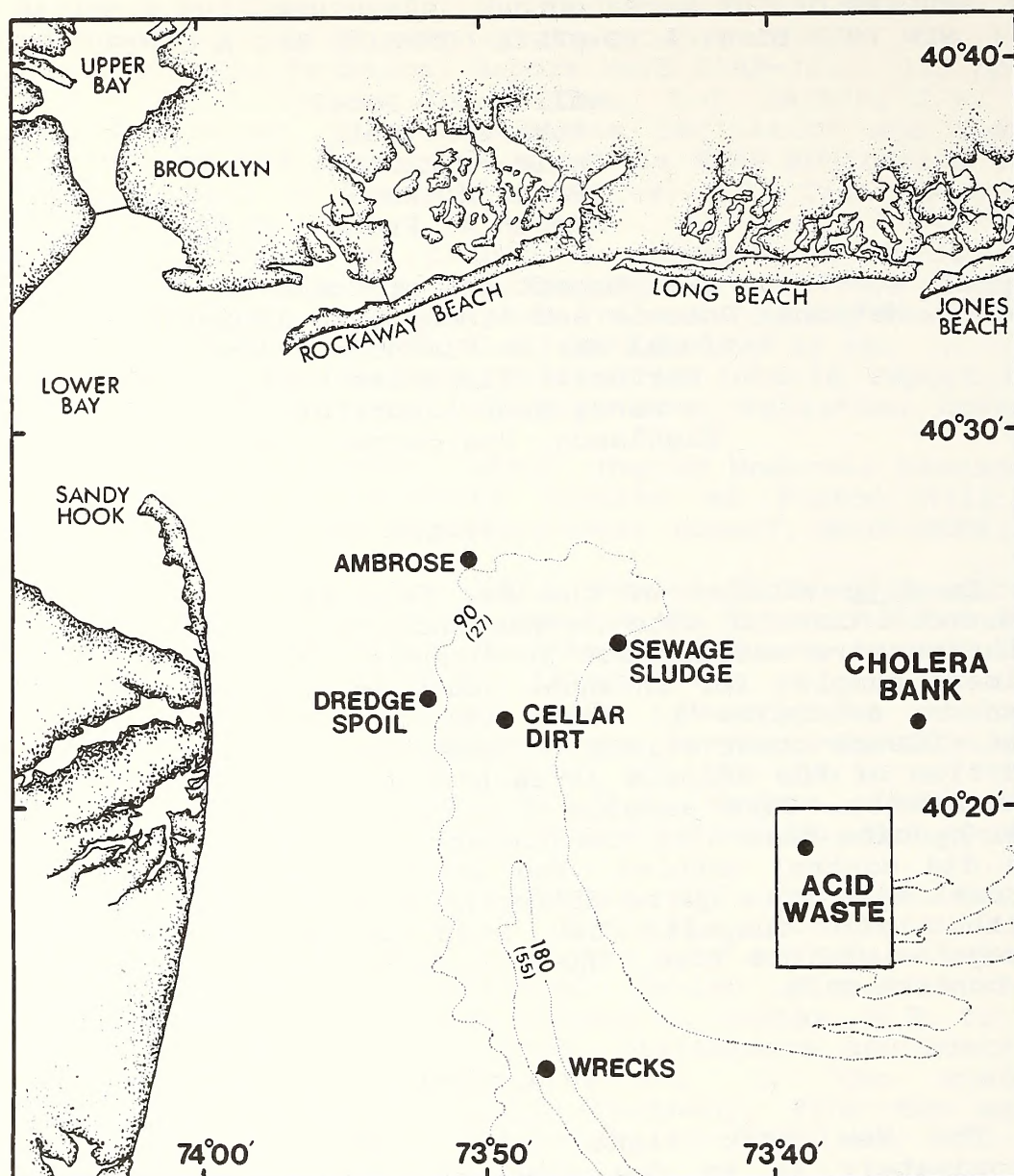


Figure 1. Sampling sites in the acid waste disposal area and Cholera Bank are designated by dots in the respective areas.

In spite of the arguments, pro and con, over the effect of the acid waste on the biota in the water column and sediments there has been little direct observation or photodocumentation to substantiate either position. We therefore decided to visually inspect the dumpsite, record these observations on video tape and collect sediment samples for analyses.

MATERIALS AND METHODS

On 3 August 1982, the R/V KYMA was moored fore and aft in the greenish-yellow stain from a dump we observed approximately one

hour before. The site was at 40°18.55'N, 073°38.80'W, based on Loran C readings, in 26 m of water. Diving operations began approximately two hours after the dump was completed using techniques and equipment designed for environments contaminated by hazardous materials (Phoel, 1978). Besides the direct visual observations of the six divers taking part in the investigation, about one hour of color video tape and five random sediment cores (78.5 cm² by 7.5 cm) were taken for infaunal analysis.

The next day the ship was moored at a site 10 km bearing 035°T from the dumpsite in 25 m of water (40°23.18'N, 073°34.70'W) in an area known as Cholera Bank. After videotaping and sediment sampling as previously described, the ship was remoored at the dumpsite where another dive was made for observations and videotaping.

One dive was made at each site to obtain the sediment samples, and five dives, covering about 360 m² of bottom each, were made for videotaping: three at the dumpsite and two at the Cholera Bank control site. Two additional dives were made at the dumpsite for visual observations only. The total dumpsite and control site dive times were 3.0 and 1.5 man hours, respectively. Video tapes were used to confirm observations, which were reported back to the ship by underwater communication rather than being obtained at post-dive debriefings.

The sediment samples for infaunal analysis were sieved to 0.5 mm, fixed in formalin and preserved in alcohol. Organisms from the cores were later sorted and identified using dissecting microscopes.

RESULTS

As the research ship approached the dumpsite, which was marked by light green waters, its propeller churned up water which was a bright yellow-green in color. Divers observed fairly clear water just under the surface with visibility about 2 m. A whitish, stringy gelatinous material, commonly observed throughout the New York Bight, was seen above the thermocline. Visibility diminished gradually to the thermocline where it was less than 20 cm due to a very fine, bright yellow floc. At 8 m the thermocline was strong and about 2 m thick. Under the thermocline the water was dark but very clear (visibility ~4 m) with pea-sized yellow-orange aggregates uniformly distributed at 10-20 m⁻³ throughout (Figure 2). Figure 2 illustrates the patch covering of the bottom by these aggregates which the current gently shifted and which tended to concentrate in troughs of sand ripples. Sediments were of a yellow-brown, medium/fine sand with large numbers of burrowing sea anemone, Ceriantheopsis americanus (see Table 1).

Observations in the acid dumpsite the following day, when no new dumps were observed, showed the water just under the surface to be clearer and the floc at the thermocline made up of larger particles. Under the thermocline the water was again dark and clear but the yellow-orange aggregates, while uniformly distributed, were less numerous in the water. The number of

aggregates on the bottom, however, had substantially increased to almost cover the bottom.

The control site, out of the direct influence of dumping activity, also had a similar strong thermocline at 8 m with surface and bottom temperatures of 24.6°C and 10.3°C respectively. The visibility just under the surface was about 3 m and remained the same down to the bottom where it was just slightly darker. Visually, the only indication of the thermocline was a light

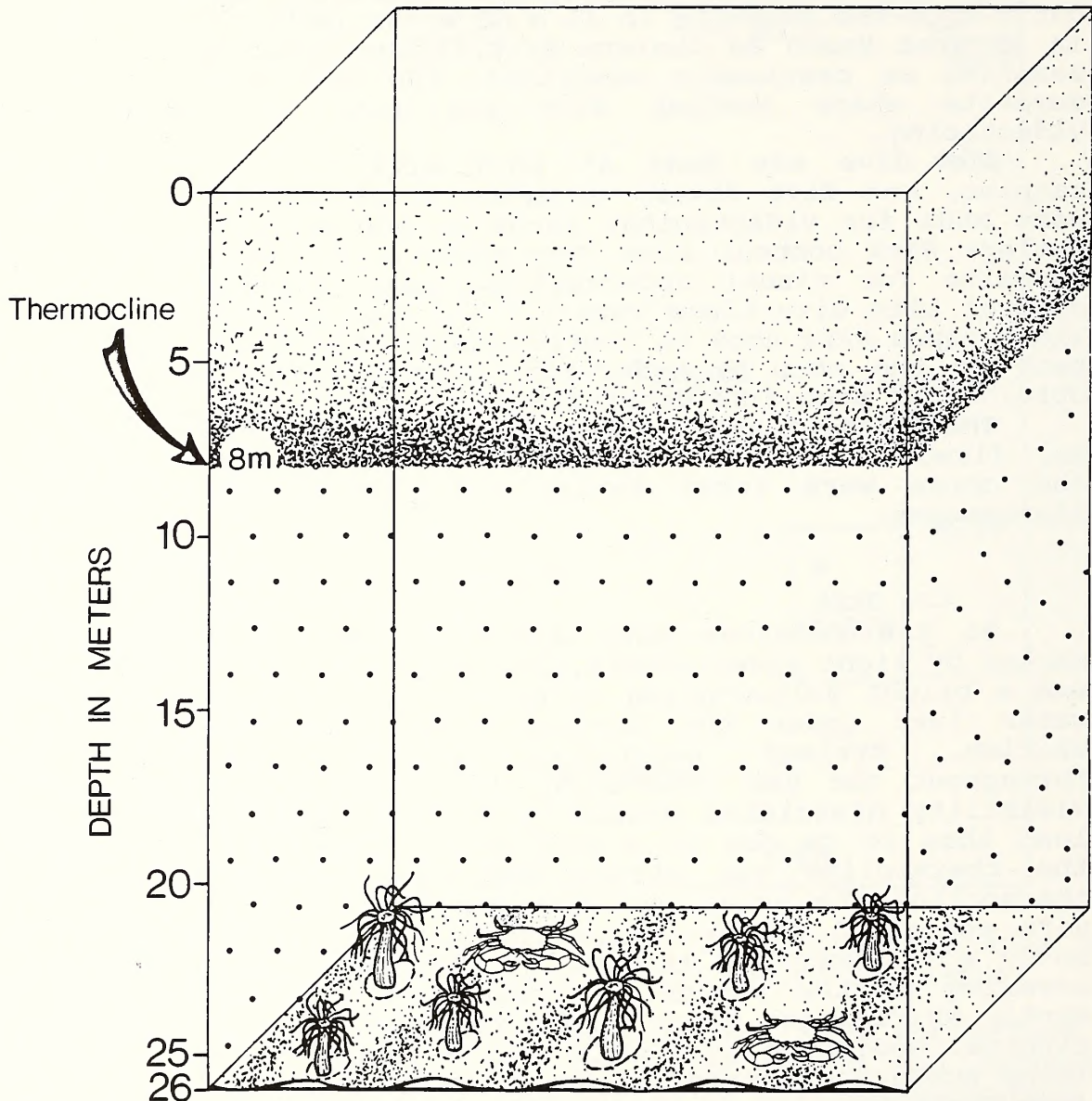


Figure 2. Conceptual drawing of the water column and seabed in the acid waste disposal site approximately two hours after a dump. The shading depicts an increased concentration of fine flocculant material on the thermocline. Below the thermocline the water is clear but dark with a uniform distribution of floc aggregates to the bottom. Numerous aggregates are depicted rolling on the seabed with high concentrations in the troughs of sand ripples. Rock crabs and the numerous anemone-like Ceriantheopsis are shown.

accumulation of the common stringy gelatinous material above it. The sediments were of brown fine sand with some dark brown organic material on the surface.

Table 1. Relative abundance of pelagic and epibenthic animals at the control and acid waste disposal sites.

Species	Acid Site	Control Site
<u>Ceriantheopsis americanus</u>	High	High
<u>Cancer irroratus</u> (adults)	Moderate	Moderate
<u>Asterias forbesi</u>	Rare and small	Occasional; larger
<u>Cliona celata</u>	Occasional	Occasional
<u>Pagurus</u> sp.	Occasional	None
Flounder (unidentified)	One	None
Ctenophores (unidentified)	High	None
Juvenile fish (unidentified)	Low	None
Shark (unidentified)	One	None
Skate (unidentified)	None	One

Table 1 compares the relative abundance of biota observed at each site. With the exception of the stringy gelatinous material present above the thermocline at both sites, no material, living or otherwise, was observed in the water column at the control site. At the dumpsite a 1.5 m unidentified shark was noted swimming slowly at the surface, ctenophores were common above the thermocline where visibility permitted observation. Juvenile fishes, 3-4 cm in length, were seen near the surface and small juveniles (1-2 cm in length) were observed among the floc particles at the thermocline. One flounder and one skate, both unidentified, were observed at the sea floor of the dump and control sites respectively. At both sites Ceriantheopsis americanus was the most abundant (ca. 20/m²) benthic species observed. Most of the C. americanus at the dumpsite had an area of 10-15 cm in diameter which was clear of aggregates around the stalk. The stalks also appeared to be higher than those at the control site. Rock crabs, identified as Cancer irroratus, and an occasional sulfur sponge, Cliona celata, were observed to be of the same size and abundance at both sites; however, only at the control site were numerous small (about 0.5 cm in length) crabs,

possibly *C. irroratus*, observed. Starfish, *Asterias forbesi*, were observed at both sites but those at the dumpsite were smaller and much less abundant than those at the control. The dumpsite had an occasional hermit crab (*Pagurus* sp.) whereas none were seen at the control.

Results of macrofauna analyses in core samples are summarized in Table 2. Number of species, number of individuals and species diversity (Shannon-Weaver) were all higher at the control site than at the acid dumpsite. Two-thirds of the difference between sites in number of individuals was due to polychaetes. Relative differences in numbers of individuals and species between sites were greatest for crustaceans.

Table 2. Summary statistics for macrofauna of acid and control sites, with numbers of individuals and species of most abundant major taxa. Data are means (\pm standard error) of five 78.5 cm² core samples.

		Acid Site	Control Site
Number of species (S)		7.6 \pm 0.6	11.4 \pm 0.9
Number of individuals (N)		11.2 \pm 1.4	26.0 \pm 3.3
Species diversity (H')		1.90 \pm 0.09	2.15 \pm 0.12
Equitability (J')		0.94 \pm 0.02	0.89 \pm 0.03
Polychaetes	S	4.4 \pm 0.7	6.8 \pm 0.6
	N	5.8 \pm 1.2	16.4 \pm 2.5
Crustaceans	S	0.2 \pm 0.2	2.4 \pm 0.8
	N	0.2 \pm 0.2	6.2 \pm 2.5
Molluscs	S	2.0 \pm 0.3	1.6 \pm 0.5
	N	4.2 \pm 1.0	2.6 \pm 1.0

DISCUSSION

During the summer, when a strong thermocline exists, the precipitated floc of ferrous and ferric hydroxides is concentrated at the thermocline. Aggregates of the floc, and probably other material, are formed and become dense enough to pass through the thermocline into the bottom waters, eventually accumulating on the sediments. The substantially higher concentrations of aggregates on the sediments compared to concentrations in the sub-thermocline waters indicate that the aggregates settle slowly onto the sediments. Without renewed input, the water column should be cleared of aggregates within a

few days; however, the persistence of the aggregates on the bottom would be determined by the direction and speed of bottom currents as well as dissolution of the aggregates. It is speculated that in the absence of a thermocline, if the density of a floc is greater than the density of water, there would be a gradual increase in floc concentration with depth and aggregate formation would take place on the bottom. If the density of the floc is not greater than that of the water the floc would remain at the surface and be rapidly dispersed by tidal currents and the rougher winter seas.

A strong north-northwesterly surface tidal current had negligible effects on the floc at the thermocline and aggregates on the bottom except for slight oscillations. As no net transport of the aggregates was observed during this period of near maximum tidal current velocity and no floc or aggregates were observed at the control site to the north-northeast, it is our tentative conclusion that storms are required to disperse the aggregates to any considerable degree, at least when a strong thermocline is present.

Table 1 indicates only small differences in abundance and size of the animals observed at each site suggesting that, for these species at least, there are no major effects of the acid wastes. A possible explanation for juvenile fish being more abundant at the dumpsite, if indeed they are, is that their predators avoid the wastes and/or cannot find prey as effectively in the floc. The latter effect could also account for the higher numbers of hermit crabs at the dumpsite; the skate, a principal predator of these crabs, was seen at the control site but not the dumpsite. The greater size or extension above the sediment observed in Ceriantheopsis at the dumpsite could be another effect of reduced predation. Obviously, more observations would be required to determine whether abundances at the two sites are statistically different.

The data in Table 2 may indicate minor effects of acid dumping on benthic macrofauna, especially crustaceans. Crustaceans as a rule are thought to be sensitive to contaminants, and apparently have been excluded from much of nearby Christiaenson Basin by pollution (Boesch, 1982). Contaminant stress could also be limiting populations of these at the acid dumpsite. Again, the small size and number of samples collected, and the lack of corresponding information on sediment grain sizes and other variables influencing benthic distributions, precludes rigorous analysis and definitive statements on differences between sites.

CONCLUSION

From our observations there generally were no obvious differences in the condition of the biota at the acid waste disposal site and the Cholera Bank control site, which is in agreement with conclusions reached by Vaccaro et al. (1972) and Arnold & Royce (1950). Only minor differences in the abundance of animals at the two sites were seen and, as the observations were temporally and spatially limited, these differences cannot be

ascribed to dumping of acid wastes. There were, however, significant differences between the sites with regard to the presence and absence of materials related to the dumped acid wastes, i.e. floc and aggregates, and an associated decrease of sunlight to the bottom of the dumpsite.

ACKNOWLEDGEMENTS

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BIOMONITORING OF DEEP OCEAN OUTFALLS IN HAWAII

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ABSTRACT

In the process of seeking waivers (for secondary to primary treatment) from EPA, the City and County of Honolulu has implemented a biomonitoring program on its deep (200') ocean outfalls using the two man submersible Makalii. The purpose of the monitoring program is to evaluate the impact of sewage effluent discharge on the indigenous populations of marine biota in the vicinity of the deep ocean outfall diffusers. From the submersible, visual counts of fish were made along a pre-determined length of pipe, videotapes and 35 mm slides were taken of any biota living on or near the outfall pipe for further analysis, and sediment samples were taken for organic content and microfaunal analysis. Results have shown that vigorous water motion removes suspended and dissolved matter rapidly and that the new ocean outfalls have acted as artificial reefs, attracting large numbers of fish, algae and invertebrates of different species. There are large aggregations of the snapper Lutjanus kasmira. This fish is of potential commercial value, and deep ocean outfalls may be future fishing sites.

INTRODUCTION

As part of a biomonitoring program required of the City and County of Honolulu by the Environmental Protection Agency deep ocean outfalls (200') are surveyed using the two man submersible Makalii, originally built as the Star II by General Dynamics. The submersible operation is funded by the National Oceanic and Atmospheric Administration (NOAA). In 1981, 1982, and 1984, field work was done to examine the effects of effluent discharge from the Sand Island outfall located off Honolulu, and the Barber's Point outfall located about 18 miles west of Pearl Harbor. The Mokapu outfall was surveyed in 1978 and 1979 (Figure 1). Specific goals were to: 1) conduct preliminary assessments of the hydraulic performance of the outfall and 2) conduct periodic assessments of the environmental impact of the discharge. In order to qualify for a waiver from secondary to primary treatment, the City and County of Honolulu maintains an intensive biomonitoring program which, consistent with goal 2, includes monitoring of benthic communities and fish populations and the analysis of infauna of the surrounding sediments.

METHODS

The submersible Makalii was used to descend to the diffuser depth. Two visual and photographic transects (both video and 35 mm) were made, one on each side of the outfall pipe down a fixed length of pipe. A species list was made of all macroinvertebrates,

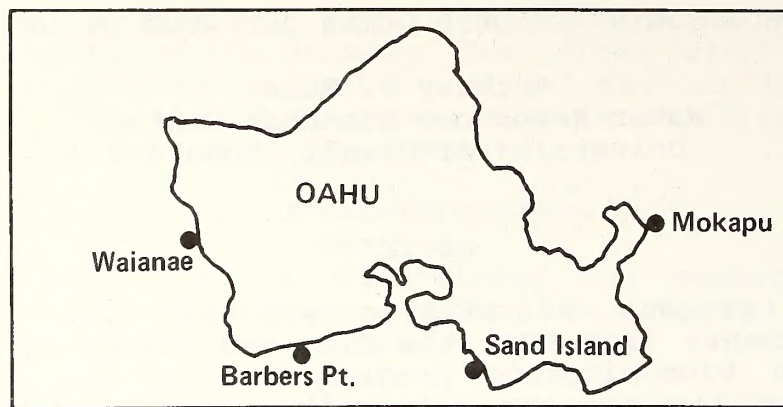


Figure 1. Sewer outfall locations, Oahu, Hawaii.

fish were counted and identified, and samples of flora and fauna were collected using the remote controlled sampling arm (arm performance was recorded on videotape and 35 mm photographs). Three replicate samples were taken of sediment for micromollusk analysis.

RESULTS AND DISCUSSION

At the Sand Island diffuser, during the 1982 dive, up to one-fourth of the visible diffuser ports appeared to be blocked or clogged with debris. Operational diffuser ports at the proximal (east) end of the pipe appeared to be discharging significantly greater quantities of effluent than ports toward the terminal end of the pipe. These qualitative differences were noted from the size and shape of effluent streams that were visible in the water column. Some ports still remained clogged during the 1984 dive. Visible effluent streams extended approximately 1 to 3 m from the diffuser port. All effluent particles and discolored water masses emanating from the diffuser ports were observed to disperse horizontally, with the prevailing current, or in an upward vertical direction. In 1981, 1982 and 1984, no effluent particles were ever observed settling on the ocean floor.

During all dives the effects on benthic sand dynamics due to the outfall structure were observed. A net seaward flow of sand appeared to be down slope in the area of the outfall pipe. Approximately half of the outfall structure (distal end) is acting as a dam to this flow of sand, with a resulting accumulation of sand on the shoreward side of the pipe and loss of sand on the seaward side. An additional observation was that the outfall pipe appeared to be rotated toward the south, perhaps from the weight of the accumulated sand pushing in that direction. The City and County of Honolulu, in order to alleviate the blockage of the discharge ports, is considering the installation of telescopic ports which rise above and discharge 6' above the pipe. Other remedies are under study.

At the Barbers Point outfall, no adverse hydrodynamic performance was observed. During dives in 1981, 1982 and 1984 all ports were discharging vigorously. No sand drift build up was

observed.

The environmental effects of the outfalls can be divided into two broad categories: alteration of the physical habitat; and alteration of the physico-chemical components of the water column and benthic surface, which in turn affects the metabolic functioning of the benthic community. At Barbers Point and Sand Island, the outfall pipe and base of armor rock provide a complex of hard substratum that is qualitatively very different from the flat carbonate sand bottom characteristic of the 200' depth. The solid surface provides attachment surfaces for sessile benthic species, while the spaces between armor rocks provides shelter for small fish and motile invertebrates. At Sand Island and Barbers Point, juvenile damselfish (Chromis leucurus) are present in large numbers. Sea urchins and sea cucumbers abound, especially adjacent to and on top of the pipes. The continuous flow of effluent material provides a supply of organic particulates to organisms residing in the pipe-rock community. Thus, sessile filter feeders that have attached to the hard surfaces and particulate feeding fish have a continuous and easily accessible food supply.

At the Mokapu outfall on the North Shore of Oahu, bryozoans have been seen (Russo et al. 1981) which indicates a moderate flux of organic material settling to the bottom. These organisms cannot exist in heavy particulate fluxes since they die by smothering. The presence of these filter feeders may be good indicators of an outfall environment with light particulate buildup (Russo et al. 1982). Bryozoans were not seen at Sand Island. During the May 1984 dive on Sand Island, large aggregations of white sponge were observed for the first time. Being filter feeders, they seem to thrive in high particulate loads.

There appeared to be no significant deleterious effects on the benthic surface from the sewage discharge at the Barbers Point and Sand Island outfalls. There is some discoloration of the sediments near the diffuser ports at Sand Island, but, sediment micromollusk analysis showed no anomalous or deleterious effects of the effluent. The sediments near the Barbers Point outfall diffuser were white, but, aggregations of sludge particles are accumulating and should persist until primary treatment begins in December 1984.

The combination of increased habitat complexity and shelter and a continual source of food may initially provide an ideal environment for populations of fish. Figure 2 shows that there was an increase in the total fishes at the Mokapu diffuser in 1979, mainly due to the appearance of the snapper taape, Lutjanus kasmira. The number of herbivorous fishes decreased in deference to the taape at both outfalls. Results of dives on the Mokapu outfall also showed a slight increase in species richness from 1978 to 1979, as the diffuser was approached. Eighty percent of the fish counted were the carnivore Lutjanus kasmira. Large numbers of surgeonfish (Acanthuridae), goatfish (Mullidae) and wrasses (Labridae) were also seen.

In 1984, conditions at Barbers Point changed dramatically: The outfall which was previously discharging at 13% of its rated plant capacity (25 mgd), began discharging raw sewage at 60%

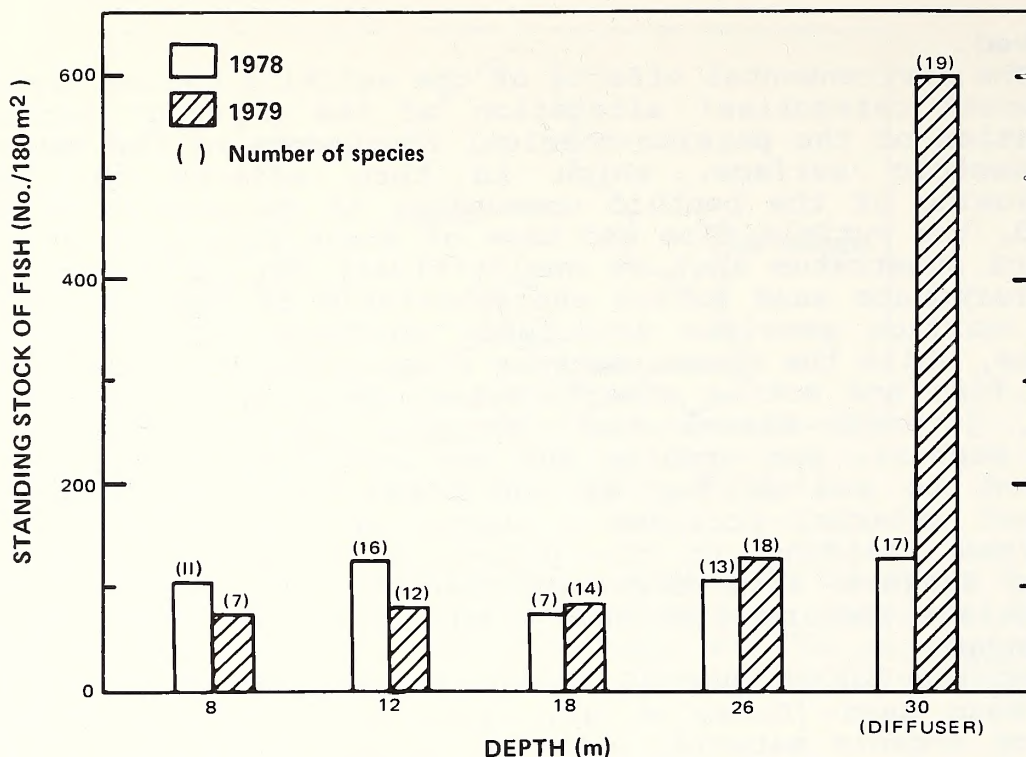


Figure 2. Relative abundance of fish at Station B on the Mokapu outfall. Ninety per cent of the fish counted at 30 m in 1979 were of one species, Lutjanus kasmira.

of its capacity. There was a noticeable decrease in fish populations, especially in the large aggregations of the yellow snapper Lutjanus kasmira. During the 1984 dive, none were seen, whereas in 1981 and 1982, they dominated the outfall fish populations (Table 1). In December 1984, primary treatment will commence and an increase in fish populations are expected in 1985. The yellow snapper (taape) may or may not recolonize the outfall environment.

The snapper taape (Lutjanus kasmira) was introduced to Hawaii in the mid '50s essentially as a potential food fish. This fish seems to disperse rapidly and to quickly exploit new habitat space. There have been dramatic increases in sightings by divers, and fishermen report significantly higher catches in recent years than normal. The total landings of taape from all the islands have increased from 1000 pounds in 1967 to 100,000 pounds in 1981, netting about \$70,000 (Tabata 1981).

Being a predator of small free swimming prey (Hobson 1974), taape may put great pressure on the juvenile fish stocks of other species seen at the diffuser, and could cause a sharp decline in diversity and abundance of fish there. Increases in taape have been reported by local fishermen, in areas where they also complain of declines in preferred species such as goatfish (Mulloidichthys and Parupeneus), big eye (Priacanthus), and squirrelfish (Myripristus). There is no scientific evidence to indicate that taape is outcompeting or overlapping in niche with these other species, however, stomach contents do indicate that the taape may be a general carnivore taking, along with

Table 1. Fish species abundance from Barbers Pt. deep dives (visual counts from the submersible Makalii).

	<u>Dec. 1981</u>	<u>March 1982</u>	<u>May 1984</u>
Family: Acanthuridae (Surgeon fish)			
<u>Naso literatus</u>	2	0	0
<u>Naso hexacanthus</u>	10	4	2
<u>Acanthurus nigoris</u>	10	15	0
<u>A. nigrofusus</u>	1	4	0
<u>Zanclus cornutus</u>	<u>3</u>	<u>4</u>	<u>6</u>
Total	26	28	8
Family: Pomacentridae (Damsel fish)			
<u>Dascyllus albisella</u>	> 50	20	2
<u>Chromis leucurus</u>	>100	>150	>100
<u>C. verator</u>	<u>>200</u>	<u>>200</u>	<u>10</u>
Total	>350	>370	>112
Family: Chaetodontidae (Butterfly fish)			
<u>Chaetodon miliaris</u>	70	>100	25
<u>C. multicinctus</u>	5	2	0
<u>C. auriga</u>	3	0	1
<u>C. fremblii</u>	2	3	0
<u>Forcipiger flavissimus</u>	2	5	7
<u>Holacanthus arcuatus</u>	1	0	5
<u>Heniochus acuminatus</u>	<u>0</u>	<u>4</u>	<u>2</u>
Total	83	>114	40
Family: Mullidae (Goat fish)			
<u>Mulloidichthys flavolineatus</u>	>100	> 50	>20
<u>Parupeneus multifasciatus</u>	5	11	6
<u>P. cyclostomus</u>	0	3	0
<u>P. porphyreus</u>	<u>5</u>	<u>9</u>	<u>0</u>
Total	>110	> 78	>26
Family: Labridae (Wrasses)			
<u>Labroides phthiophagus</u>	2	2	0
Family: Balistidae (Trigger fish)			
<u>Balistes</u> spp.	2	0	0
<u>Melichthys niger</u>	<u>1</u>	<u>5</u>	<u>3</u>
Total	3	5	3
Family: Scaridae (Parrot fish)			
<u>Scarus</u> spp.	2	0	0
Family: Lutjanidae (Snappers)			
<u>Lutjanus kasmira</u>	>500	>500	0
Family: Holocentridae (Squirrel fish)			
<u>Myripristis murdjan</u>	8	>20	0
TOTAL	<u>>1083</u>	<u>>1117</u>	<u>>189</u>

crustaceans, juveniles of the above mentioned species. There is no indication that taape is eaten by its cohabitators (Tabata 1981). Whether or not there is a reciprocal density dependent relationship between taape and its cohabitators is not clear, but, a definite increase in abundance of this fish over the last 20 years and its rapid dispersal to all islands is well documented.

Even though taape is fished, it is considered of secondary importance as a commercially valuable fish. It is only taken when other more commercially valuable fish are absent. The low demand for taape by consumers and fishermen simply lies in the fact that it is a colorful yellow fish with pale flesh. Local fish consumers traditionally prefer "red" fish. Most consumers who try taape consider it as tasty as the other commercially valuable reef and shore fish. The University of Hawaii Sea Grant Program has begun a campaign to "re-educate" fishermen and consumers about the palatability and market value of taape. Progress is slow; traditions die hard as most fishermen still consider the taape as a "junk" fish (Tabata 1981). If these cultural biases can be removed and the demand for taape increased, along with its price per pound, the culling of this species will not only be of commercial value, but also ecologically efficacious since it will insure the stability and diversity of the fish community. Since sewer outfalls attract large aggregations of taape and its cohabitators, these areas could be used as fishing grounds (Russo et al. 1979). Taape are readily caught with gill nets and purse seines and, since Hawaiian sewer outfalls are presently at depths between 30 and 60 meters (100-200 ft), the outfalls are easily accessible to fishermen.

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WATER QUALITY OF NEWLY DISCOVERED SUBMARINE GROUND WATER
DISCHARGE INTO A DEEP CORAL REEF HABITAT

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ABSTRACT

The detection and measurement of water quality from submarine ground water discharge (SGWD) into a deep coral reef habitat was made in the Key Largo National Marine Sanctuary. The significance of this discovery is the importance of the water quality to perturbation and productivity of deep coral reef habitats and the contributions to sea floor processes at the sediment/water interface. SGWD was collected at 35 m in two localities in the sanctuary between November 29 and December 3, 1983 using seepage meters. Flow rates were ~ 3 l/hr at the first site and ~40 ml/hr at the second site. Water sampled directly from the meters at both sites showed oxygen values of 0.30 and 2.32 mg/l, respectively; and, 10 ppt salinity at the first site. Analyses of the water from both sites showed numerous pesticide peaks and heavy metal concentrations 100 -10,000X above mean sea water values. These results indicate a high potential for perturbation of benthic organisms that exist at the sediment/water interface where SGWD may exist.

INTRODUCTION

This is the first report of submarine ground water discharge into a deep coral reef habitat, and into the Key Largo National Marine Sanctuary specifically. The significance of this discovery is important because of the implications to the productivity and perturbation of coral reef ecosystems. Localized submarine ground water discharges along the southeastern Atlantic coast have been known for some time (Manheim, 1967). However, most studies have dealt with localized inputs from seepages or springs in shallow water, or ground water discharges that have been detected in deep water (≥ 200 m) and as far as 120 km offshore. There appears to be no research on inshore discharges (≤ 50 m) between these two extremes, particularly in reference to discharges which may enter the ocean bottom through unconfirmed aquifers over a large area. The data reported by Manheim (1967) contained salinity measurements, as evidence of fresh water presence, but did not contain information regarding pollutants and nutrients which would be important to benthic ecologists.

Kohout (1966) and Kohout and Kolipinski (1967) appear to be the first investigators to study the importance of fresh water seepage to marine ecosystems. Their studies were conducted in

south Florida along the shore of Biscayne Bay. After studying the relationship between biological zonation and ground water discharge in Biscayne Bay, they concluded "... the distribution of the organisms correlates so closely with the underlying hydrological factors that a conclusion appears justified: the distribution of the organisms is primarily a function of salinity related to ground water discharge."

Johannes (1980) presented the most definitive work on the ecological significance of submarine ground water discharge. While Johannes (1980) acknowledged the fact that ground water discharge to the sea is widespread, he pointed out that "...overlooking the fact could lead to serious misinterpretations of ecological data in studies of coastal pollution, of benthic zonation and productivity, and of the flux of dissolved substances between bottom sediments and overlying water." Johannes studied the shallow water areas off Perth, Australia and found the submarine ground water discharge delivered several times as much nitrate to coastal water as did river discharge. In his concluding statements, Johannes emphasized the need for additional research examining the influence of ground water discharge on benthic communities.

Ground water entering a marine habitat can have two different effects. It could either stimulate the productivity of benthic communities through nutrient influx, or it could be toxic due to contaminant influx. The prevailing quality of submarine ground water could be an important factor in affecting the health of benthic communities and the prevailing zonation of organisms.

METHODS AND MATERIAL

Ground water discharge was collected at 35 m in two localities in the Key Largo Marine Sanctuary (Fig. 1) between November 29 and December 3, 1983 using seepage meters as described by Lee and Cherry (1978) and Lee (1980). At the first site off French Reef, two 55 gal metal drum heads, located approximately 10 m apart, were used as seepage meters. The drum heads were 56.5 cm in diameter and had a 15.2 cm wall. They were worked into the sand/coral bottom until the side opposite the collection port touched the bottom. The top was tilted slightly so the collection port side was elevated approximately 2.5 cm. On December 3, we moved to a site off Carysfort Reef where a plexiglass dome was used as a seepage meter. The dome was 30.5 cm in diameter and was worked into the sediment approximately 5.0 cm. Water samples discharging from the seepage meters were collected in 1000 ml Nalgene bags.

Water samples from the seepage meters were sorted in BOD bottles that had been rinsed in concentrated HCl, acetone, and deionized distilled water. Samples were refrigerated, kept on ice, and returned to Virginia Tech for analyses.

The water samples were filtered to remove the heavy precipitate of iron oxides. They were then treated with enough phosphoric acid to lower the pH to 2.0. Pesticides were extracted with ethyl ether for phenoxy herbicides; 90% hexane and 10% benzene for general chlorinated hydrocarbons and organic phosphates; and, chloroform for triazine herbicides. Extracts

were analyzed by flame photometric detection (Tracor Model MT 220), by electron capture using a nickel 63 detector (Tracor Model MT 220), and/or by flame ionization using a nitrogen/phosphorus detector (Hewlett Packard Model 58308). Methods of analyses followed Environmental Protection Agency Manual of Analytical Methods (1980) with specific modifications by the Virginia Tech Pesticide Residue Laboratory.

Water samples were analyzed for heavy metals on a Perkin Elmer (Model 460) atomic absorption spectrophotometer. Oxygen was measured using a microwinkler technique based upon the oxygen method of Strickland and Parsons (1972). Salinity was measured with a calibrated YSI S/C/T meter (Model 33).

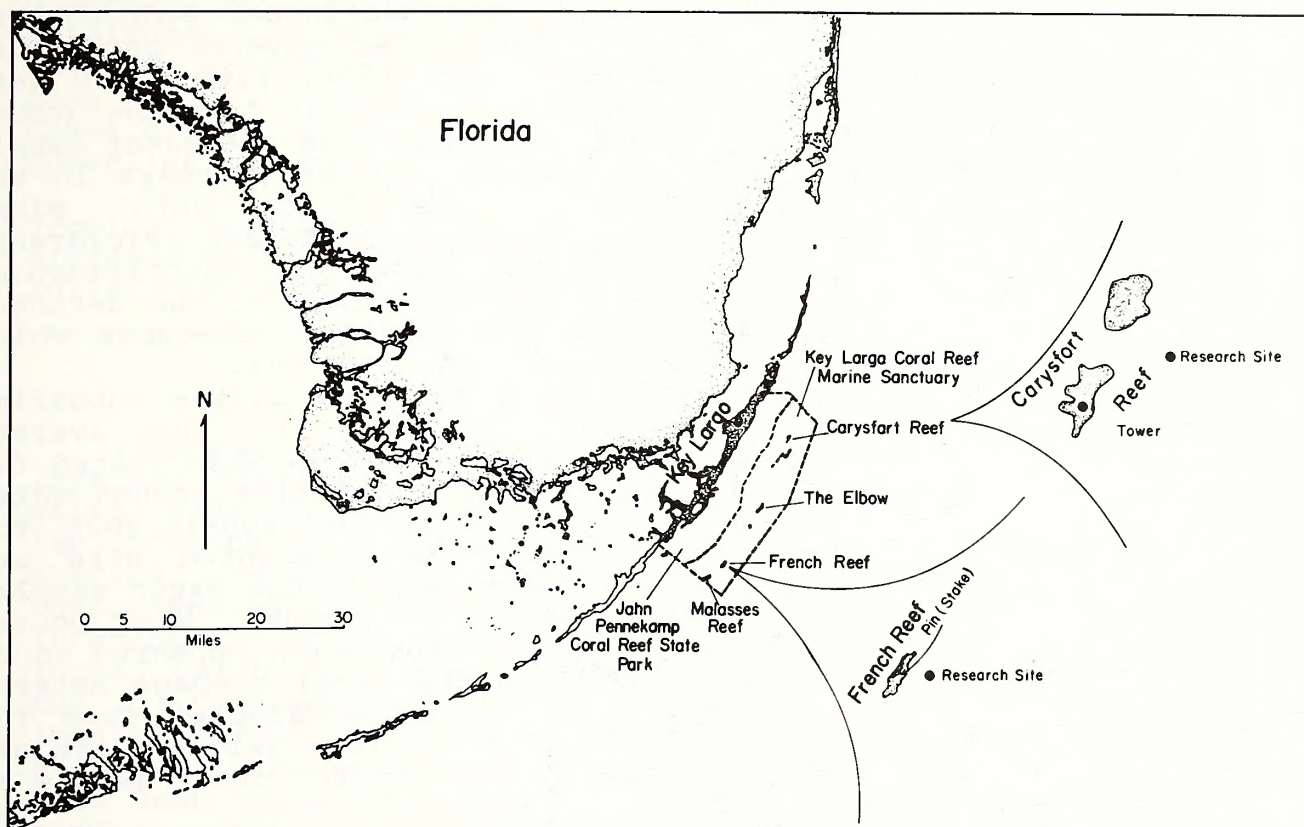


Figure 1. Research sites in the Key Largo National Marine Sanctuary.

RESULTS

By direct observation, we measured 400 ml in eight minutes or 50 ml/min issuing from one of the seepage meters off French Reef at our first site. This represented $199.2 \text{ ml/m}^2/\text{min}$ or $286.8 \text{ L/m}^2/\text{day}$. The lowest salinity measured in the latter aliquots issuing from this meter decreased to 10 ppt and oxygen decreased to 0.3 mg/l . Ambient salinity of the Gulf Stream was approximately 33 ppt and ambient oxygen at 35 m was $\sim 6.0 \text{ mg/l}$.

At the Carysfort site, the bottom was a fine-grained depositional area with no evidence of shells or coral fragments. A thin film of cyanobacteria covered the bottom and were the only visible sign of life. No seepage canals were evident in the bottom. Here we collected 600 ml in 15 hrs after the plexiglass dome was allowed to flush for 2 hrs. This discharge volume represented 13.2 l/m²/day. Water sampled directly from the dome was found to contain 2.32 mg/l of oxygen; whereas, ambient sea water contained 5.8 mg/l of oxygen.

The nematocide MoCap (O-Ethyl S, S-dipropyl phosphorodithioate) was the only pesticide clearly identifiable. The concentration in the submarine ground water was 0.061 ug/l. There were at least seven other peaks in the hexane/benzene extraction used for organophosphate and chlorinated hydrocarbons that cannot be identified at this time. Also several phthalates were isolated in the hexane/benzene extraction. Five peaks were isolated in the chloroform extraction (triazines) from the ground water sample off French Reef and eight peaks from the water sample off Carysfort. There were also approximately eight peaks in the ethyl ether extraction from samples at both sites (phenoxyherbicides), and one peak suggestive of Tordan (Picloran). It is not possible to be more precise about the identification until more material is collected. Moreover, many of the detected peaks are probably derivatives of the original compounds which makes the task of identification even more difficult.

The concentration of heavy metals measured in the submarine ground water samples is listed in Table 1. The average concentration of these ions found in sea water is also listed for comparative purposes. These data show the submarine ground water discharge had concentrations of heavy metals 100-10,000X the average value for sea water. The values presented here are probably lower than the original levels because the water samples were filtered prior to analyses. All water samples, when poured into the B.O.D. bottles contained a red floc which appeared to be an iron oxide. This was expected from the metal seepage meters, but it was also characteristic of the water samples from the plexiglass meter as well. Filtration of the iron oxides certainly reduced the iron levels and probably some of the other metals as well.

Table 1. Concentration of Heavy Metals in Ground Water off Key Largo and an Average Value for Sea Water (Brewer, 1975).

	<u>French Reef</u>	<u>Carysfort</u>	<u>Sea Water</u>
Copper	0.199 mg/l	0.221 mg/l	.05 ug/l = .00005 mg/l
Cadmium	0.171 mg/l	0.228 mg/l	.10 ug/l = .00010 mg/l
Chromium	0.043 mg/l	0.067 mg/l	.3 ug/l = .0003 mg/l
Iron	3.740 mg/l	0.840 mg/l	2.0 ug/l = .002 mg/l
Zinc	0.703 mg/l	0.570 mg/l	4.9 ug/l = .0049 mg/l
Lead	0.592 mg/l	0.592 mg/l	.03 ug/l = .00003 mg/l
Mercury	0.596 ug/l	0.247 ug/l	.03 ug/l

The submarine ground water discharges also were analyzed for dissolved nitrate (Table 2). The nitrate values show that submarine ground water discharge can be an important source of fixed nitrogen compounds in the area. We measured 0.100 mg/l off French Reef and 0.103 mg/l off Carysfort Reef.

Table 2. Concentration of nitrate in ground water off Key Largo and a comparison with values from other known submarine ground water sources.

	<u>Nitrate conc.</u>	<u>Source</u>
French Reef	0.100 mg/l	Simmons, 1983 cruise
Carysfort	0.103 mg/l	Simmons, 1983 cruise
Discovery Bay, Jamaica:		
Undiluted spring water	1.120 mg/l	D'Elia et al. (1981)
Average ground water	8.750 mg/l	D'Elia et al. (1981)
Guam	0.113 mg/l	Marsh (1977)
Caves off St. Croix	0.058 mg/l	Szmant-Froelich (1983)
Coastline, Perth,	1.610-	
Australia	5.320 mg/l	Johannes (1980)
Tropical Inorganic		
Nitrogen in Tropical	0.014-	
Surface Sea Water	0.028 mg/l	Spencer (1975)

DISCUSSION

There are many ways that ground water can become contaminated (Pye and Patrick, 1983). Some of these include land disposal of solid and liquid waste, industrial and domestic wastewater impoundments, the agricultural use of pesticides, sewage disposal systems, and deep-well disposal of liquid wastes. The problem is compounded by the fact that when the constituents of such wastes interact in the ground water environment, new compounds may be formed which will vary in their toxicity. Due to the nature of the slow movement of ground water, the contaminants may remain localized over long time periods and may not be diluted as rapidly as they would be in a surface water supply. Many contaminants have been found in higher concentrations in ground water than in surface water.

Ground water contamination is an insidious type of water quality degradation because it occurs underground, unobserved, and unrecorded. The sources of contamination are not easily identified, and the contaminants go undetected until the damage is done. Once detected, the effects are often irreversible and little can be done to correct the ground water quality problem.

Florida is one of ten states reviewed in detail by Pye and Patrick (1983). They site 92 known contamination incidents, 58 of which affected or threatened water supplies. Florida also was one of three states that reported problems arising from agricultural practices. Given the charge by Johannes (1980) and the review by Pye and Patrick (1983), it is interesting that Duursma and Smies (1982) reviewed the processes related to pollutant transfer through marine sediments and did not mention submarine ground water influence, which again probably reflects the lack of

research on this topic.

Even though coral reefs are highly productive and generally resilient ecosystems, they are easily perturbed by natural and man-made disturbances (Endean, 1976; Pearson, 1981). Endean (1976) listed the major factors of human activity known to adversely affect coral reefs and all dealt with surface activities. Admittedly, many activities such as sewage disposal, dredging, mining, and land clearing cause adverse effects, but no mention was made of ground water effects. Pearson (1981) stated that it may take coral communities several decades to recover from a natural disturbance (hurricane, cold weather, fresh water dilution), and the picture is even less clear in man-made disturbances where the environment may have undergone permanent change. Endean (1976) also pointed out how little was known about the effects of pesticides on coral reef ecosystems.

In the case of coral reef ecosystems, perturbation could be magnified through the dual effect of pesticides (chlorinated hydrocarbons and related toxins) and herbicides (photosynthetic inhibitors). If the concentration of photosynthetic inhibitors was high enough in the ground water to kill symbiotic zooxanthellae, corals could die as quickly as if the pesticide level was high enough to kill the coelenterate component. The persistent and continuous demise of Florida's coral reefs could possibly be explained, in part, by the chronic influx of pesticide contaminated ground water over past decades.

The lack of information on heavy metal effects is equally apparent (Endean, 1976). Perhaps this stems from the fact that most investigators have ignored the possible significance of submarine ground water influx.

Coral reef ecosystems stand in stark contrast to all factors which influence coastal productivity. They generally exist on the fringes of tropical islands which produce little fresh water runoff; they are flushed by surface ocean waters usually depleted in nutrients (Stoddart, 1969); and, their associated sediments are coarse, calcareous, and have little silt or organic matter (Sepkoski, 1971; Patriquin, 1971). In spite of these factors, coral reef ecosystems are regarded as one of the more productive and diverse ecosystems on our planet (Odum, 1971). Such high productivity could not exist without mechanisms to conserve, cycle, and replenish nutrients (Welsh, et al., 1979).

A number of such mechanisms are known. While it is beyond the scope of this paper to include all mechanisms, some of the more recent and major processes include such examples as the association of the coral coelenterate and their symbiotic algae (Goreau et al., 1971; Taylor 1973; Muscatine and Porter, 1977); the role of seagrasses and their decomposition products (Welsh, et al., 1979; Zieman et al., 1979); the role of bacterial colonization on the mucus nets of coral and the subsequent use of such mucus strands as food (Sorokin, 1973; Lewis, 1977a, 1977b; Ducklow and Mitchell, 1979); the role of fish utilization of seagrass and nutrient transfer through waste products to corals (Meyer et al., 1983), and the transfer of nutrients from sediments and feces trapped in reef holes and crevices (Szmant-Froelich, 1983). In spite of these conservative cycling

processes, the search for nutrient sources and methods of conservation are still important paradigms in coral reef research (Szmant-Froelich, 1983).

Even though fixed nitrogen compounds appear to be the most frequently limiting nutrient in the marine environment (Muscatine and D'Elia, 1978), several investigators have reported the contribution of such compounds by SGWD. Marsh (1977) studied the nutrient content of ground water input to a shallow reef flat on Guam and found that ground water seepage had a major influence on nutrient levels. D'Elia *et al.* (1981) also studied shallow ground water inputs (~ 2 m) to Discovery Bay, Jamaica and found that such seepage provided a significant enrichment of nitrogen to the bay. Johannes (1980) found nitrate levels between 1.610-5.320 mg/l along a 5 km strip of coastline bordering Perth, Australia. Meyer *et al.* (1983) found 0.016 mg/l and 0.004 mg/l of NH_4^+ adjacent to reefs with and without fish, respectively. Szmant-Froelich (1983) recently reported high nitrate levels "burping" from coral caves where she believes nutrients are being regenerated from decompositional processes. There appears to be little doubt that submarine ground water discharges will contain fixed nitrogen compounds that can have a beneficial effect on associated benthic communities. The prevalence of such contributions by SGWD and the importance of fixed nitrogen compounds to the nitrogen budget of coral reef ecosystems deserves additional study.

SUMMARY

Ground water can be a double-edged sword, particularly in areas like the Florida Keys. In remote coral reef areas, submarine ground water influx may be the source of nutrients, particularly phosphate and fixed nitrogen compounds, which would be beneficial to the coral reef ecosystem. In highly industrialized and populated areas, submarine ground water discharge may cause perturbation of coral reefs and contribute to their eventual demise.

Because the coral reefs of Florida are economically important to the state and are part of state and national sanctuaries, it is of the utmost importance to know the quantity and quality of existing submarine ground water discharges.

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CHAPTER IV

SEA FLOOR PROCESSES

SUBMERGED EVIDENCE OF PLEISTOCENE LOW SEA LEVELS
ON SAN SALVADOR, BAHAMAS

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ABSTRACT

On a carbonate island such as San Salvador, Bahamas, there are several prominent geologic features that are indicative of past sea level positions: reef terraces, wave-cut benches and notches, and horizontal solution conduit systems. Work on the subaerial geology of the island has provided evidence for several episodes of high sea level positions during the past 130,000 years. Use of the Johnson-Sea-Link I research submersible to investigate portions of the submarine geology of San Salvador has led to the recognition of several prominent indicators of low stands of sea level. A preferred horizon for bench or platform development has been found at -55 m. It can be speculated that these represent reef-constructive and/or wave-cut features formed during a sea level stillstand at -55 to -50 m. Additionally, wave-cut notches and overhangs and horizontal solution conduits that open onto the island wall occur at a preferred elevation of -105 m. One large solution conduit was also located at -125 m. Horizontal solution conduits at preferred horizons in a uniform lithology argue for a stillstand in sea level at those elevations for a time period of at least a few thousand, to tens of thousands of years. These features are documented evidence for low sea level stillstands at those elevations, but as yet their chronology has not been established.

INTRODUCTION

Limestone bedrock is vulnerable to solution by acidic meteoric and ground waters. The presence of carbon dioxide in the atmosphere and within the soil produces carbonic acid, which provides the acidity to drive the solution of limestone on a large scale in natural environments. The landscape produced by solutional processes is unique and is called a "karst" landscape, after the type locality in Yugoslavia (Jennings, 1971).

Karst landscapes are characterized by sinking streams, springs, closed depressions of a variety of sizes and shapes, and caves. It is the internal drainage of all or part of the landscape by solution conduits (or caves) that allow the unusual surface topography to occur. Contained within the mass of the

landscape, caves are protected from the weathering that obliterates evidence of past conditions on the surface. The size, shape, flow markings, sediments and mineral deposits of caves are a direct measure of the conditions on the surface. Valleys, as they widen and deepen, often remove the features of earlier times. Caves, however, adjust to new lower levels and leave behind abandoned upper levels with all their included information preserved.

When surface waters in karst areas sink, they travel downward until a barrier to their flow is reached. This barrier is usually an insoluble lithology or the water table. The position of the water table, in turn, is controlled by local and regional base levels. In a situation of abundant and uniform limestone rocks free of insoluble layers, the elevation of abandoned cave passages is a measure of past base levels. Conduit size can be measured, and paleowater velocities can be estimated from flow markings called ablation scallops on the walls. This yields an estimate of conduit discharge (cross sectional area \times velocity = discharge). Sediments in the cave passage provide relative dates, provenance and fossil material. Calcite deposits such as stalagmites can be dated by U/Th techniques. From such accumulated data the nature of change on the surface, and the chronology of the changes can be established. Throughout the world, detailed studies of caves and their deposits have provided a wealth of information about the Pleistocene Epoch.

San Salvador Island, Bahamas (Figure 1) has been examined for caves to piece together a picture of the Pleistocene climatic variations and sea level positions. The island offers unique advantages that allow a maximum data return for effort expended.

MATERIALS AND METHODS

San Salvador Island was selected for this research for many reasons. First, it has an established field station with access to the necessary research tools. Second, it is an isolated, small platform that remains discrete during glacial eustatic sea level changes. Third, it is a tectonically stable platform subsiding isostatically at a known rate, so tectonic noise is filtered out of estimations of sea level change. Fourth, the island is uniformly limestone to a great depth, so an excellent karst landscape is developed, and base level is tied to sea level. Fifth, the surface rocks are all Pleistocene or Holocene in age, providing boundary conditions for the genesis dates of any feature found within the rock.

The accessible solution conduits on the island have been studied in detail, and substantial information on Late Pleistocene sea level highstands has been gathered. This has been reported in detail elsewhere (Carew and Mylroie, 1983; Carew et al., 1984), and will only be summarized here.

As the island is tectonically stable (Mullins and Lynts, 1977), marine lithologies, such as fossil reefs, exposed subaerially today must have formed at an earlier, higher sea level. Solution conduits found above sea level today must have formed in a fresh water lens positioned by a highstand in sea level. The island contains numerous outcrops of marine rock, the

most notable being the Cockburntown fossil reef on the west side of the island (Figure 1). The reef extends for over 700 m as a ridge rising to 3.5 m above current sea level. Uranium/Thorium age dating of corals in the reef fix the age of the reef at approximately 125 ka. Amino acid racemization age dates on shell material from the reef also fit this time frame, and provide calibration for amino acid racemization elsewhere on the island. Sea level 125 ka ago is thought to have been at +6 m (Bloom et al., 1974), and the San Salvador data is in basic agreement. Numerous solution conduits or caves on the island contain phreatic (or water table) solution features that have an upper limit of +6 to +7 m. This requires that the water table be in this range at past times; placed at this elevation by a high sea level. Dating of the wall rock, an eolian calcarenite, enclosing the conduits at Lighthouse Cave (Figure 1) by amino acid racemization shows the rock to have an age of approximately 85 ka. Sea level had to drop below present levels at 85 ka for the eolian calcarenite (which extends down to -2 m) to form, then rise to approximately +6 m to develop the solution conduit, probably during the 80 to 70 ka time span (Boardman et al., 1983; Cronin et al., 1981). Uranium/Thorium dates from stalagmites within the cave show air-filled conditions at 50 ka. Sea level was below -1 m at 50 ka as

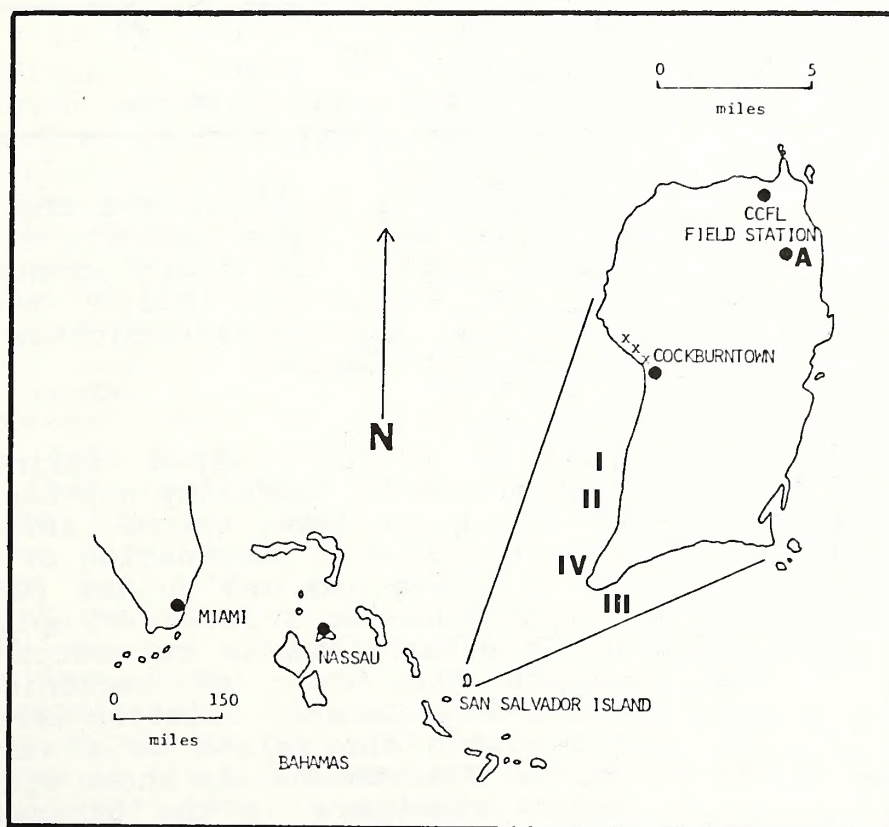


Figure 1. Location map of the Bahama Islands showing San Salvador Island and features discussed in the text: A = Lighthouse Cave; I, II, III, IV = dive sites; xxx = fossil reef.

the stalagmite, a subaerial feature, began to form. Stalagmite growth ceased and a marine layer, indicative of a return to present sea level, occurred sometime between 47 and 35 ka. Stalagmite growth resumed after 35 ka, indicating a sea level below present until the Holocene. The sea level curve produced from interpretation of this data is shown in Figure 2.

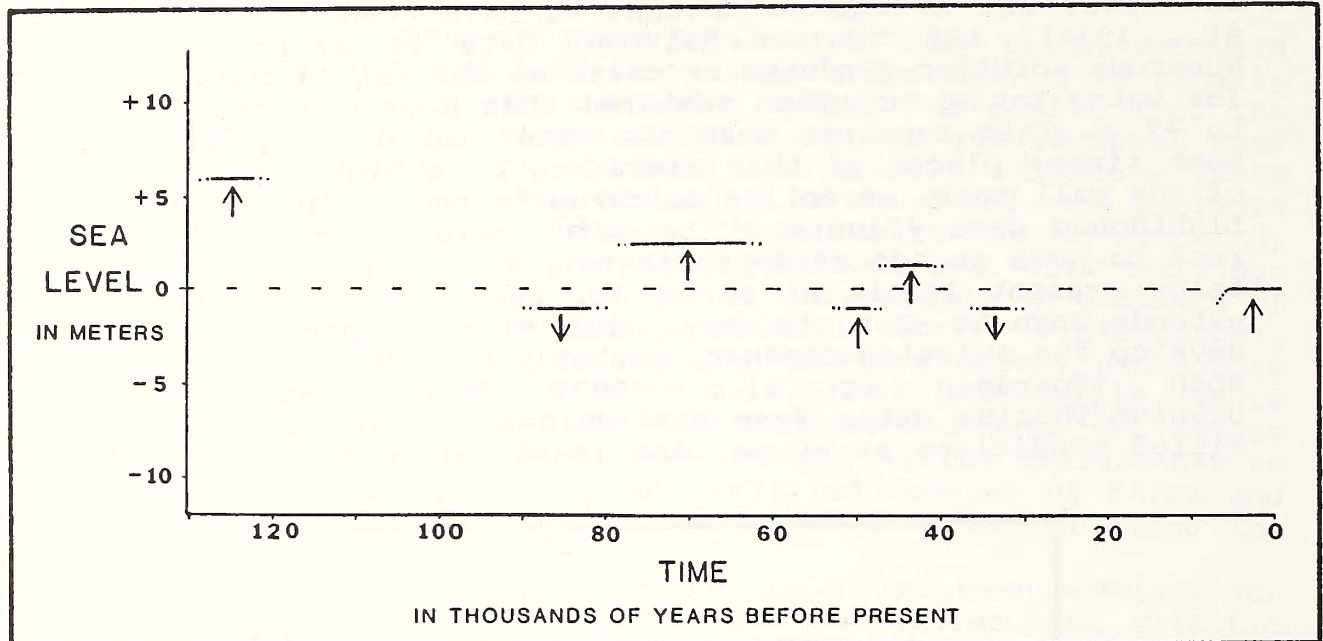


Figure 2. Constraints on sea level position over the last 130,000 years. Lines with upward pointing arrows indicate high sea level at or near the displayed elevation. Lines with downward pointing arrows indicate sea level somewhere below the displayed elevation. Data collected by submersible indicates stillstands at -55, -105, and -125 m, as yet undated.

The data described above has helped refine the Late Pleistocene sea level curve, but by necessity has been restricted to identifying and dating high sea level stands. Investigation of low sea level stands has necessitated examination of tectonically uplifted areas, such as Barbados and New Guinea (Bloom et al., 1974). This requires assumptions about rates of uplift that are difficult to establish. An alternative is to search for markers of low sea level beneath the ocean on tectonically stable platforms, such as San Salvador Island. Solution conduits can be expected to have formed within the island at a variety of sea level stillstands during the Pleistocene, as shown diagrammatically in Figure 3. Scuba divers elsewhere in the Bahamas (Williams, 1979; Palmer, 1982, 1984) have entered conduits at depths of up to -50 m, but deeper penetration is difficult and dangerous. Prior to 1982 little information was available on solution conduit development below normal scuba range.

Exploration for solution conduits over the entire Pleistocene

eustatic sea level range requires the use of a submersible. This allows descent to the lowest probable sea levels (-125 to -150 m), and detailed examination upward from that depth. The submersible used needs to be maneuverable and provide optimum visual reconnaissance capability. Through the Harbor Branch Oceanographic Institution and the College Center of the Finger Lakes Bahamian Field Station, access was gained to the Johnson-Sea-Link I submersible. A preliminary reconnaissance was done on the west wall of San Salvador Island in October 1982, and a broader search was done at adjacent locations on the island's wall in October 1983.

The search pattern involved dropping directly to -180 m then working upward. If a favorable depth could be determined, a horizontal search would check for additional conduits. A 35 mm slide and videotape record was kept of the dives. Videotapes of dives off San Salvador during other research projects were examined to see if conduits could be identified.

RESULTS

One dive was made in October of 1982 in order to assess the feasibility of the program. No solution conduits were found, but the exceptional capabilities of the Johnson-Sea-Link I for this type of search were clearly demonstrated. The dive was done on the west side of San Salvador Island in southern Fernandez Bay (Dive I, Figure 1), from a depth of -300 m to the surface. The starting depth was well below the expected depth of any conduits, but by starting deep, cavities and voids produced by depositional or non-solution processes could be characterized. This allowed true solution conduits to be accurately identified on later dives. The dive also demonstrated that at depths shallower than -60 m to -75 m, recent coral growth and other biologic activity made conduits difficult to locate. This depth range is at the lower limit of scuba capability, and data at these shallower depths can be obtained from cave diving in Blue Holes. A clearly defined bench was located at -55 m on this dive.

In October 1983, three dives were conducted (Figure 1). Additional data from dating the Cockburntown fossil reef had indicated that isostatic subsidence was minimal, and conduits developed by low sea level stands would not be expected below -150 m. The dives were therefore begun in the -170 to -180 m depth range and continued upward on the wall with horizontal traverses at depths that showed promise, because surface work on subaerially exposed conduits showed that they often clustered along the base level horizon formed by past high sea level. Detailed examination of conduits exposed on the sea cliffs provided an excellent model of what to look for at depth. These conduits were in the 0.5 m to 1.0 m diameter size range.

Dive II was done in southern Fernandez Bay, south of the previous year's (Dive I) site. Dive III was done in French Bay, near Sandy Point, an area of proven conduit development at past high sea levels (Mylroie, 1983). Dive IV was done just off Grotto Beach, another area associated with high sea level conduit development. The dive site locations are shown in Figure 1.

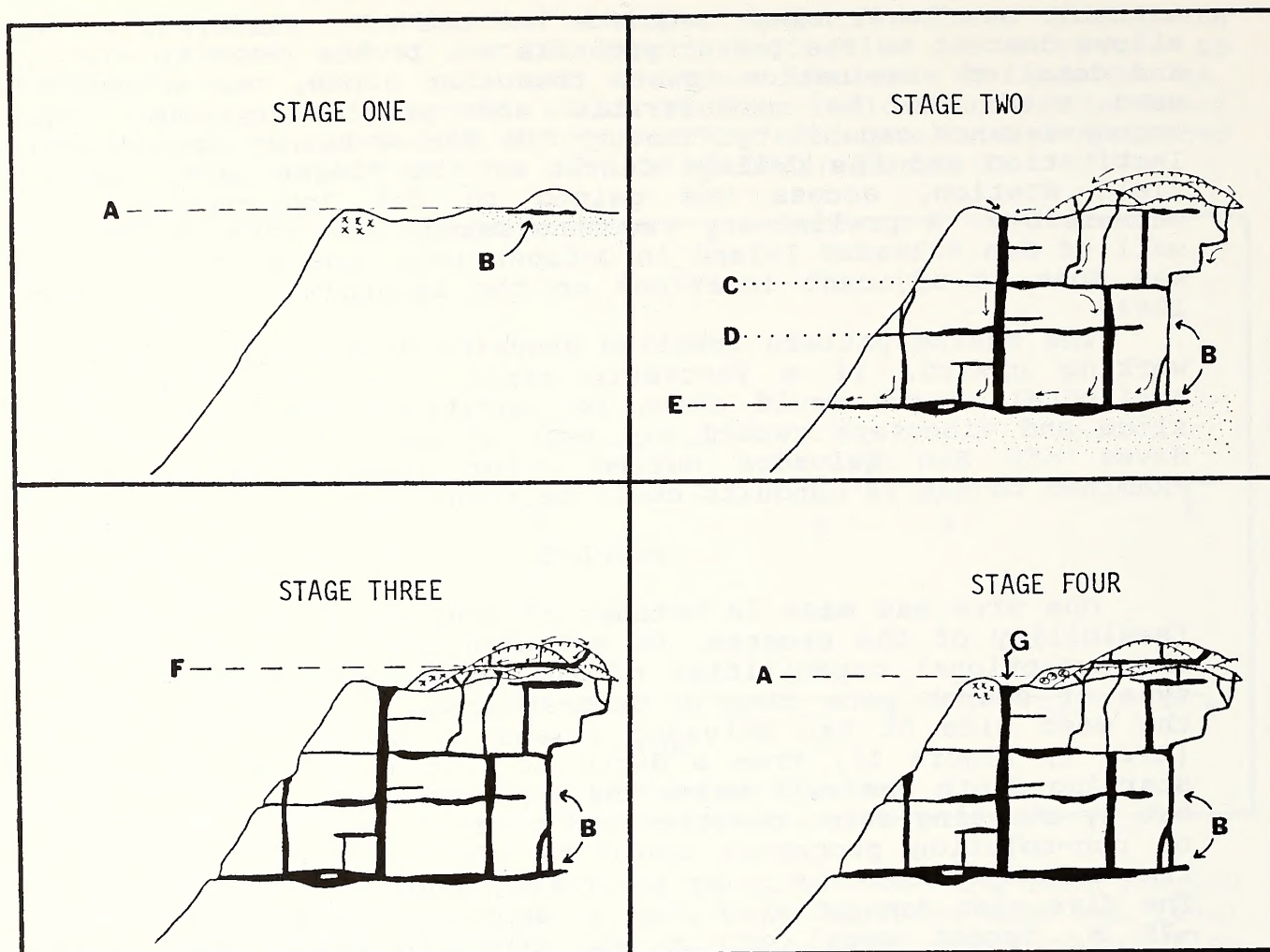


Figure 3. History of Pleistocene cave development in the Bahamas: A = present sea level; B = solution conduits; C and D = sea level stillstands during Pleistocene glaciations; E = lowest Pleistocene sea level; F = interglacial high sea level; G = Blue Hole; dots = freshwater lens; x = reef.

Stage one: Stable, preglacial conditions (sea level arbitrarily placed at present levels). Cave development as solution conduits is dependent on land being available to support a fresh-water lens.

Stage two: Falling sea level due to glaciation promotes increased formation of eolian calcarenite dunes as the entire platform is subaerially exposed. The freshwater lens drops with each lowering of sea level producing solution conduits preferentially at elevations of sea level stillstands.

Stage three: Interglacial high sea level stands produce solution conduits at elevations above present sea level. Lower conduits become flooded with marine water, depending on the size and configuration of the freshwater lens.

Figure 3 (cont.). Stage four: Present conditions. Blue Holes provide access directly into the island solution conduit system. Reefs produced during previous sea level highstands are subaerially exposed. As each glacial cycle is repeated, the solution conduit system becomes increasingly complex.

Dive IV located two conduits at -125 m. One conduit was less than 0.5 m in diameter, the other was approximately 1 m in diameter. Dives II, III and IV all located numerous conduits, many 1 m or greater in diameter, at a specific depth of -105 m. This depth was also characterized by notches and overhangs similar to what is seen on existing wave cut cliffs on the island. During Dives II and IV, a prominent bench was located in the -50 to -55 m depth range. The benches were of variable width from 5 to 100+ m, and often included adjacent pinnacles that ended at the same depth.

A preliminary examination of eight previous dive videotapes run during other research projects revealed two additional solution conduits both at -105 m. One of these dives was in Fernandez Bay, the other on a seamount north of the island.

DISCUSSION

Data from four dives aboard the Johnson-Sea-Link I on San Salvador Island, plus review of eight videotapes from other dives, is a fairly meager data set when compared to the length of the coast of the entire island. Despite this, definite horizons of probable past lower sea level stillstands have been identified at two depths, and a third depth has been implicated (see Figure 2). Three of the four dives encountered a flat bench at -50 to -55 m. This can be interpreted either as a wave-cut erosional feature, or as a reef depositional feature. Either interpretation places wave activity in the vicinity of -50 m. Biological overgrowth obscures possible conduits at this shallow depth, and none were observed. The absence of wave-cut benches at greater depths is problematical. Evidence of an apparent former subaerial sea cliff exists at -105 m. We did not look for benches shallower than -50 m.

Solution conduits were located on three of four dives at -105 m. Videotapes of two other dives also show conduits at this depth. This depth coincides with an apparent drowned sea cliff, and large number of conduits were formed, within a very narrow vertical range of no more than a few meters. No current was observed in any of the conduits, but as they relate to an abandoned freshwater regime, this is not surprising. The presence of these solution conduits at a preferred horizon in a uniformly soluble lithology argues for a stillstand in sea level at -105 m for a minimum of a few thousand to tens of thousands of years. The abundance of the conduits suggests high discharges in a competitive manner, and this has implications for rainfall volumes during the time of conduit formation. Unlike the larger platforms to the west, San Salvador experiences a minimal increase in meteoric catchment area as sea level falls, thus allowing boundary conditions to be placed on the source of the discharge of the conduits.

The location of two conduits at -125 m on Dive IV has the same implications as conduits at -105 m. The paucity of the data prevents a conclusive argument for a low sea level stillstand at -125 m.

The preliminary reconnaissance made with the Johnson-Sea-Link I is very encouraging. Conduits have been located, and at apparently preferred depths. Two goals remain to be addressed: first, to continue reconnaissance and prove that the -105 m and -125 m levels persist, and to look for other possible levels; second, while past low sea level elevations have been identified, they haven't been placed in a chronological framework. The surficial work on San Salvador was able to date the high sea level solution conduits by forming a time window between wall rock age on one hand, and subaerial precipitate (stalagmites) age on the other. A submersible based sampling capability needs to be developed that would allow the collection of submerged conduit wall rock and conduit contents for dating purposes.

Manned undersea reconnaissance has proven feasible for the location of solution conduits produced at past lower sea levels. Further work should resolve the preferred conduit positions, and locate conduits that would be prime sites for sample collection for dating purposes. Submersibles allow access to the lower ranges of Pleistocene sea level fluctuations that are difficult to reach through SCUBA diving.

ACKNOWLEDGEMENTS

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THE BLAKE ESCARPMENT -- A PRODUCT OF
EROSIONAL PROCESSES IN THE DEEP OCEAN

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ABSTRACT

The Blake Escarpment, east of Florida, is a steep submarine cliff that extends from water depths of about 1000 to 5000 m and forms the eastern boundary of the Blake Plateau. An initial hypothesis that the modern escarpment was formed by accretion and erosional retreat was based solely on interpretations of seismic profiles. However, diffractions in the seismic record obscured the morphology of the cliff face. Dives in the submersible DSRV ALVIN, at locations where multichannel seismic reflection profiles cross the escarpment, have resulted in a new understanding of the feature's development. Observations from the submersible indicated that the slope of the escarpment approached 80°-90° in many areas, and that exposed rocks are Lower Cretaceous limestone that was deposited in the quiet interior of a carbonate bank. Erosional agents that presently are modifying the cliff face include strong currents, abrasion by biogenic sand, and unloading that results in extensive jointing and fragmenting of the rock. It is estimated that the cliff face has retreated as much as 15 km since its formation by accretion through reefal upbuilding.

INTRODUCTION

The work described here represents an effort to use a research submersible, DSRV ALVIN, to confirm or deny a hypothesis based on geophysical data concerning the formation of the Blake Escarpment, a steep cliff on the sea floor east of Florida (Figure 1). The typical continental margin is characterized by a relatively flat continental shelf and, to seaward, a somewhat steeper continental slope and gently sloping rise. Off the southeastern United States, the continental slope (Florida-Hatteras slope; Figure 1) is interrupted at about 600-m depth by the broad, flat Blake Plateau. The plateau is terminated to seaward by the Blake Escarpment, which descends steeply from about 1000 m down to almost 5000 m. This escarpment, if exposed, would be one of the most spectacular mountain fronts on earth.

The origin of the Blake Escarpment has been a puzzle. Naturally, its steep, linear nature might suggest a possible structural (faulted) origin in some tectonic settings, but this is inconsistent with our knowledge of development of trailing-edge

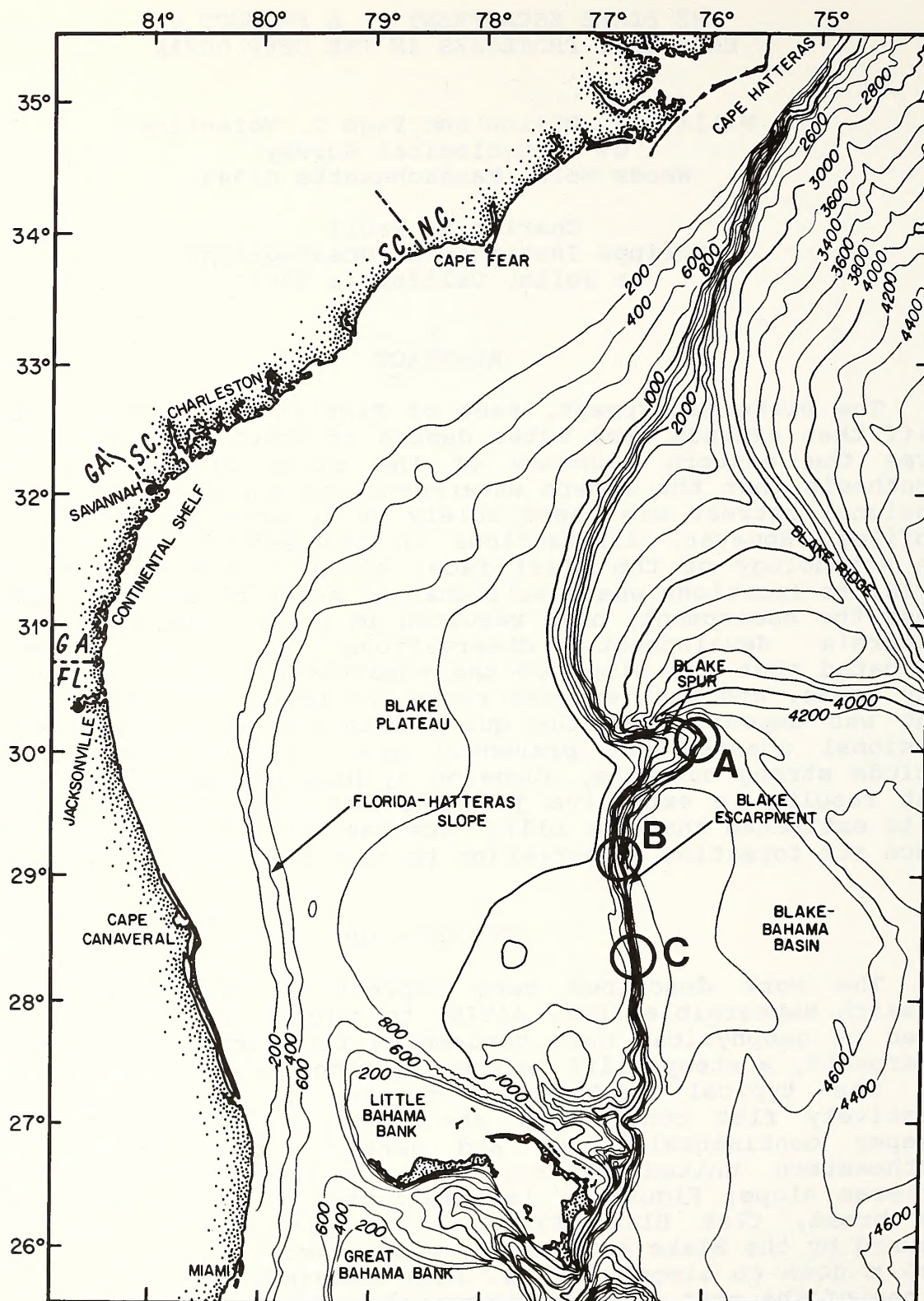


Figure 1. Bathymetry of the continental margin off the southeastern United States and locations of dive sites shown by circles. Depths are in meters.

continental margins, such as the U.S. eastern margin, where broad regional subsidence without much active faulting is the dominant tectonic style. Recent interpretations have focused on two alternatives: (1) a simple accretional model, in which the escarpment is formed dominantly by reefal upbuilding (Dillon et al., 1979; Sheridan et al., 1981); or (2) an accretional-erosional model, in which the escarpment is formed by major accumulation of carbonate platform rocks followed by extensive erosional retreat (Paull and Dillon, 1981).

To help resolve the problem, we made ten submersible dives from the top of the escarpment down to ALVIN's maximum dive depth of 4,000 meters, completing three transects of the escarpment at sites A, B and C (Figure 1). Seismic-reflection profiles along these three transects and extending to the east and west are shown in Figures 2, 3, and 4, respectively.

METHODS

The multichannel seismic reflection profiles were collected by Teledyne Exploration Company, under contract to the U.S. Geological Survey. The seismic source consisted of four 540-in (8850-cm³) airguns fired simultaneously. The seismic streamer was 3600 m long and contained 48 recording sections; the 24 sections nearest the ship were each 100 m long. The data from each section were recorded separately and subsequently were computer-processed and stacked to create the profiles (Figures 2, 3, and 4).

The submersible, DSRV ALVIN, is highly maneuverable and, at the time we used it, had a maximum operating depth of 4000 m. Observation is afforded by three ports, one for the pilot and one each for the two scientific observers. Internal observer-hand-held cameras are connected to external strobe lights (Figures 9 and 11) and external automatic cameras take photographs at selected intervals (Figures 5, 6, 7, 8 and 10). An external video camera was used to tape the entire dive. Samples of rock were obtained using the submersible's two mechanical arms with claws, one electrically powered (more maneuverable) and one hydraulically powered (more powerful). The claws were also used to hold small corers and scoop samplers for sediment sampling.

RESULTS

Geophysical Data and Interpretations

Prior to diving onto the escarpment, hypotheses explaining the escarpment's development were based on geophysical data and a few scattered samples of dredged rock. The geophysical studies were based on acoustic data (echo sounder and sidescan-sonar data and seismic-reflection profiles) as well as on magnetics and gravity data. The acoustic data are extremely difficult to interpret in an area of steep slopes such as the Blake Escarpment, as shown by Figure 2, which illustrates the difficulty of identifying escarpment features in a seismic profile (and in most echo sounder profiles, as well). The profile shows the outer Blake Plateau on the left and the deep sea floor to the right.

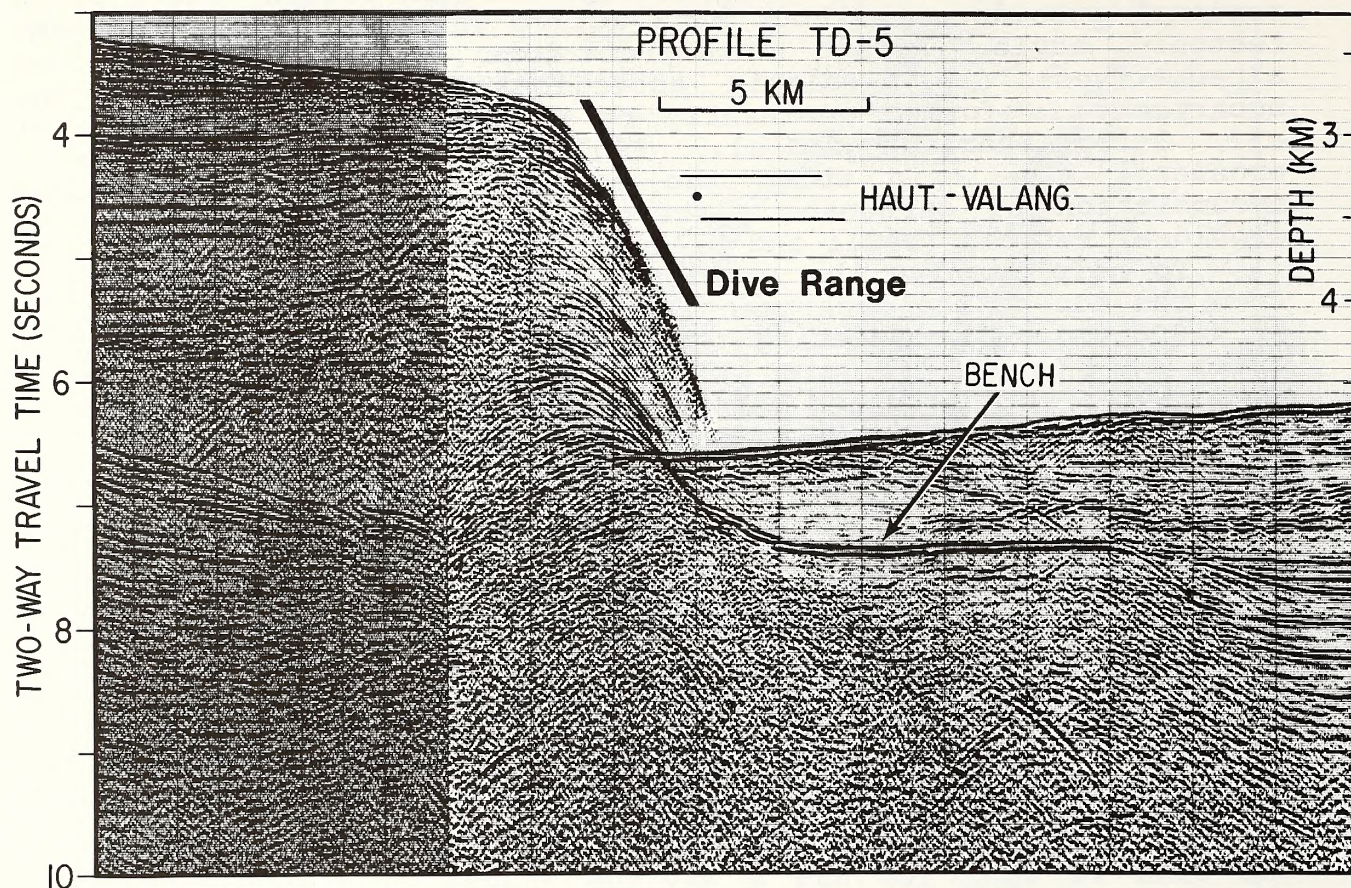


Figure 2. Multichannel seismic reflection profile passing east-west through dive site A (Figure 1). Four dives were made here. The vertical scale is in travel time of sound and therefore the vertical scale varies, depending on velocity of media. A depth scale based on water velocity is shown on right side of figure. Vertical exaggeration, based on water velocity, is 4:1.

The steep escarpment is hidden behind a set of hyperbolic reflections that appear because the profiling system does not focus its sound rays downward, but rather records echo returns from many directions. The first return comes from the nearest reflecting point, whether it is directly beneath the ship in front, behind, or off to the side. If the ship is slightly to seaward of a steep cliff, the acoustic returns from the cliff will obscure the sea floor beneath the ship and echoes from the upper part of the escarpment will obscure the lower part. Therefore, it is impossible to examine a steep slope by seismic means using ordinary surface-towed equipment. In order to see the Blake Escarpment, we had to dive and, in effect, maneuver the sub inside the displayed hyperbolic envelope of echoes. Despite the difficulties in interpretation, the seismic profiles do provide evidence that suggests major erosional retreat of the Blake

Escarpment. First, even though we could not make exact measurements, it was clear to us that the steepness of the slope exceeded values that could possibly be created by reefbuilding or any other accretionary process over such a vertical range (4000 m). We also discovered a buried bench within the sediments seaward of the base of the escarpment (Figures 2 and 3). The top of the bench was continuous with an erosional horizon in the deepsea deposits, and strata are truncated at the bench surface. These facts suggest that the bench represents a cut into the old platform edge that removed a triangular section of rock and that the toe of the slope has retreated at least 12 km at the site of Figure 2, suggesting that erosion is active now, as well as having operated in the Oligocene (the probable age of the bench; Tucholke, 1979). The profiles also show no pile of debris at the

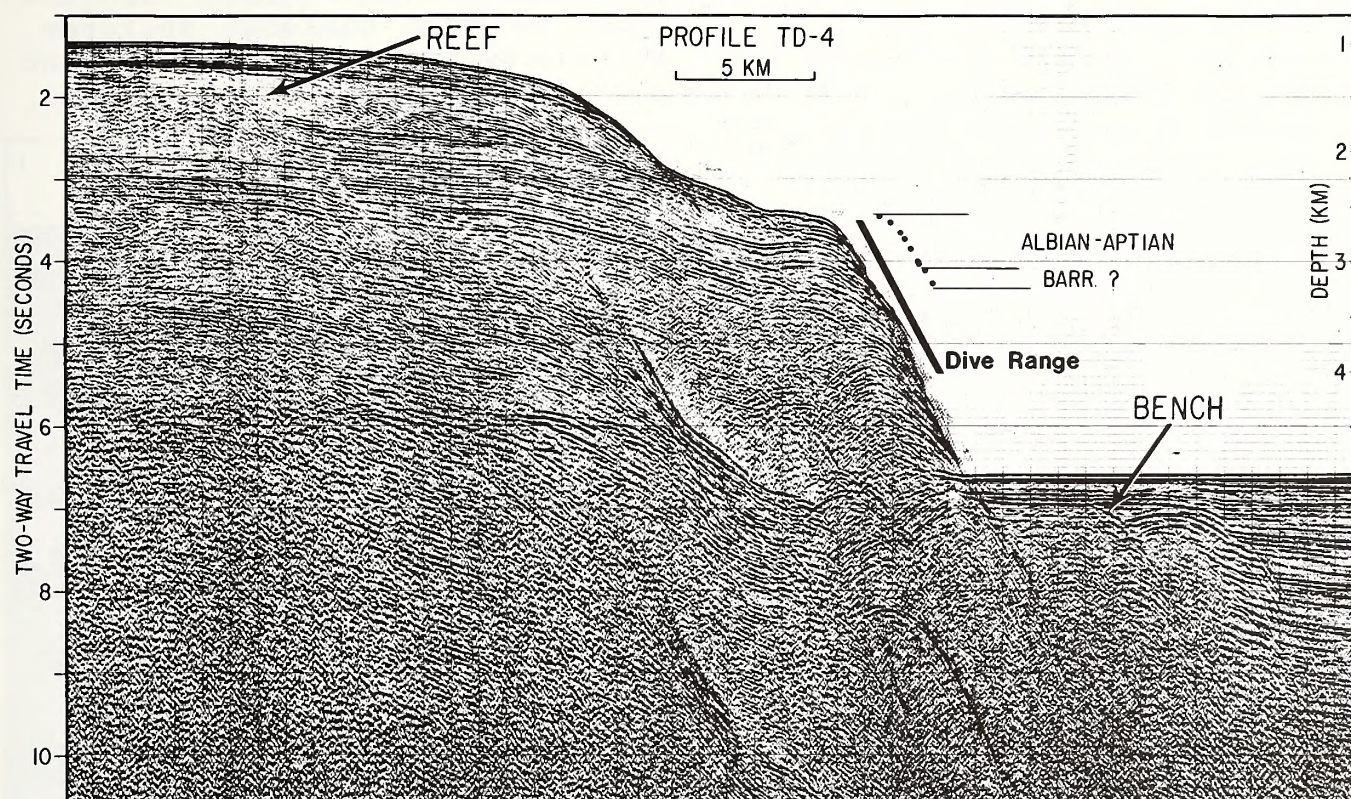


Figure 3. Multichannel seismic reflection profile passing east-west through dive site B (Figure 1). Three dives were made here. Vertical exaggeration in water is 4:1.

foot of the escarpment (Figures 2, 3, 4), but rather a deepening toward the escarpment, again suggesting active erosion. Finally, structures are truncated at the escarpment. The profile in Figure 4 is somewhat less difficult to interpret because the slope is less steep. It shows a truncated reef (inferred from seismic pattern) at the top of the escarpment and truncated reflectors part way down.

Observations from Deep Dives

Dive observations showed that much of the escarpment was nearly vertical, particularly at site A where the escarpment slope appeared to average about 80° over the depth range of the dives (Figure 2). This is illustrated by Figure 5, which is a photograph taken along a near-vertical outcrop that shows octocorals growing horizontally outward from the wall.

The environments of deposition that are indicated by studies of rocks sampled by ALVIN from the cliff provide support for the hypothesis of major erosional retreat. These rocks have been formed from sediments that were deposited in quiet waters of a carbonate bank interior, like the present Bahama Banks, commonly in shallow, in some cases, intertidal depths. Rocks that are formed in reefs or bank-edge structures, built where wave activity is at the perimeter of a carbonate bank, show the effect of a turbulent environment. No doubt, the seaward side of the carbonate platform was characterized by such bank-edge features, and the presence of bank interior facies, sampled at the present cliff, implies that considerable rock was removed by erosion.

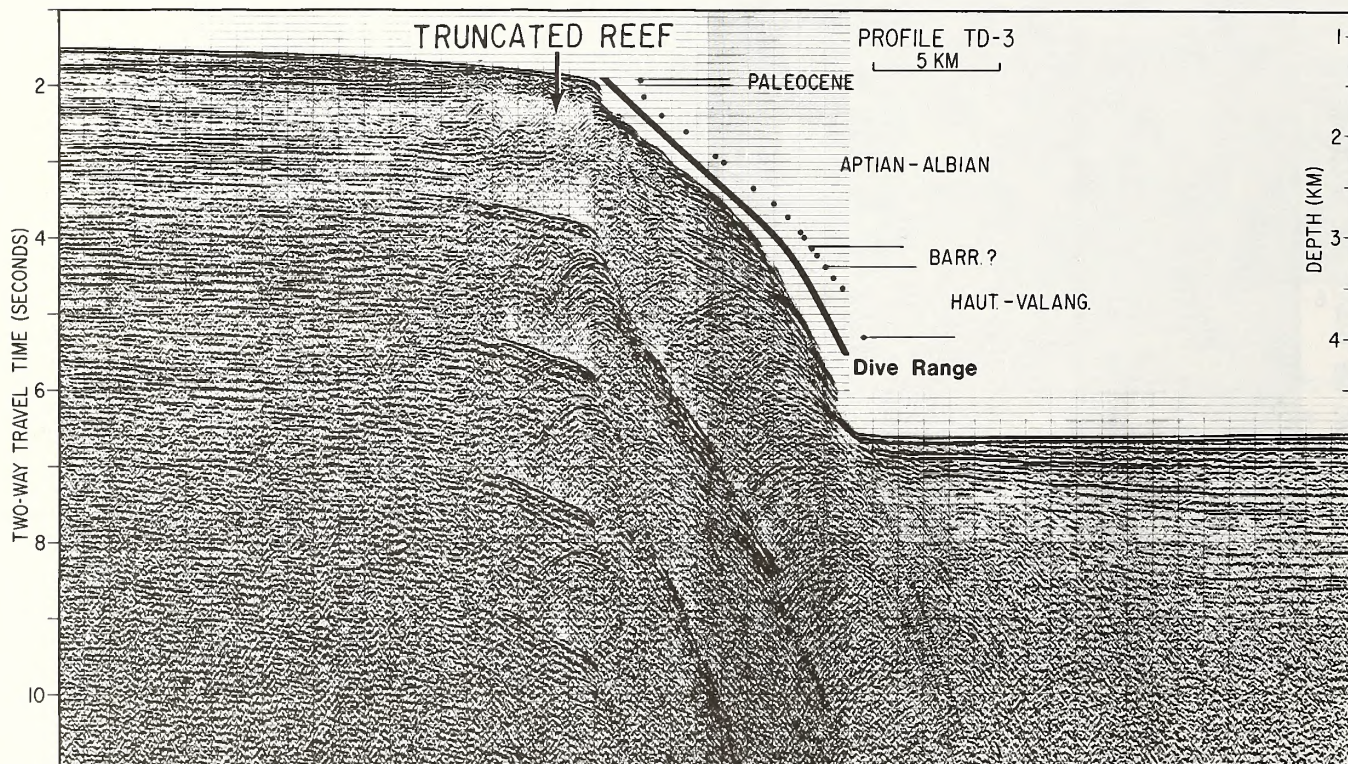


Figure 4. Multichannel seismic reflection profile passing east-west through dive site C (Figure 1). Three dives were made here. Vertical exaggeration in water is 4:1.

Rocks in the cliff face were found to be extensively jointed (Figures 6 and 7), probably resulting from an uneven release of load (Nichols, 1980). In this case, an uneven release of pressure apparently is being caused by removal of rock to seaward of the present cliff. Thus, development of joints is the product of

erosion, but it also facilitates erosion by causing fragmentation of the massive rock. Figure 6, is a horizontal view of an outcrop face, whereas Figure 7 is a downward view of stratum that has been exposed by erosion, and fractured into flagstones along joints. Often, joint blocks collapse after erosion has removed support, and jointing and erosion produce a stepped cliff face (Figures 8 and 9).

In some cases, erosion is facilitated by large variations in lithification. For example, Figure 10 shows several layers of light-colored, soft, Cretaceous lime mud interlayered with hard, brittle, dark-coated limestone rock of the same age. The soft layers can be eroded away easily, removing support for rock above them, and resulting in collapse.

Erosion by mechanical means requires currents and abrasives to grind away the rock. We experienced currents up to approximately two knots along the cliff face, which caused considerable difficulties in maneuvering ALVIN and damage to the sub when it was swept into outcrops. The strong currents apparently employ as abrasive the modern biogenic sand, commonly formed of pteropod remains, that accumulates in areas of reduced current (note lower part of Figure 9).

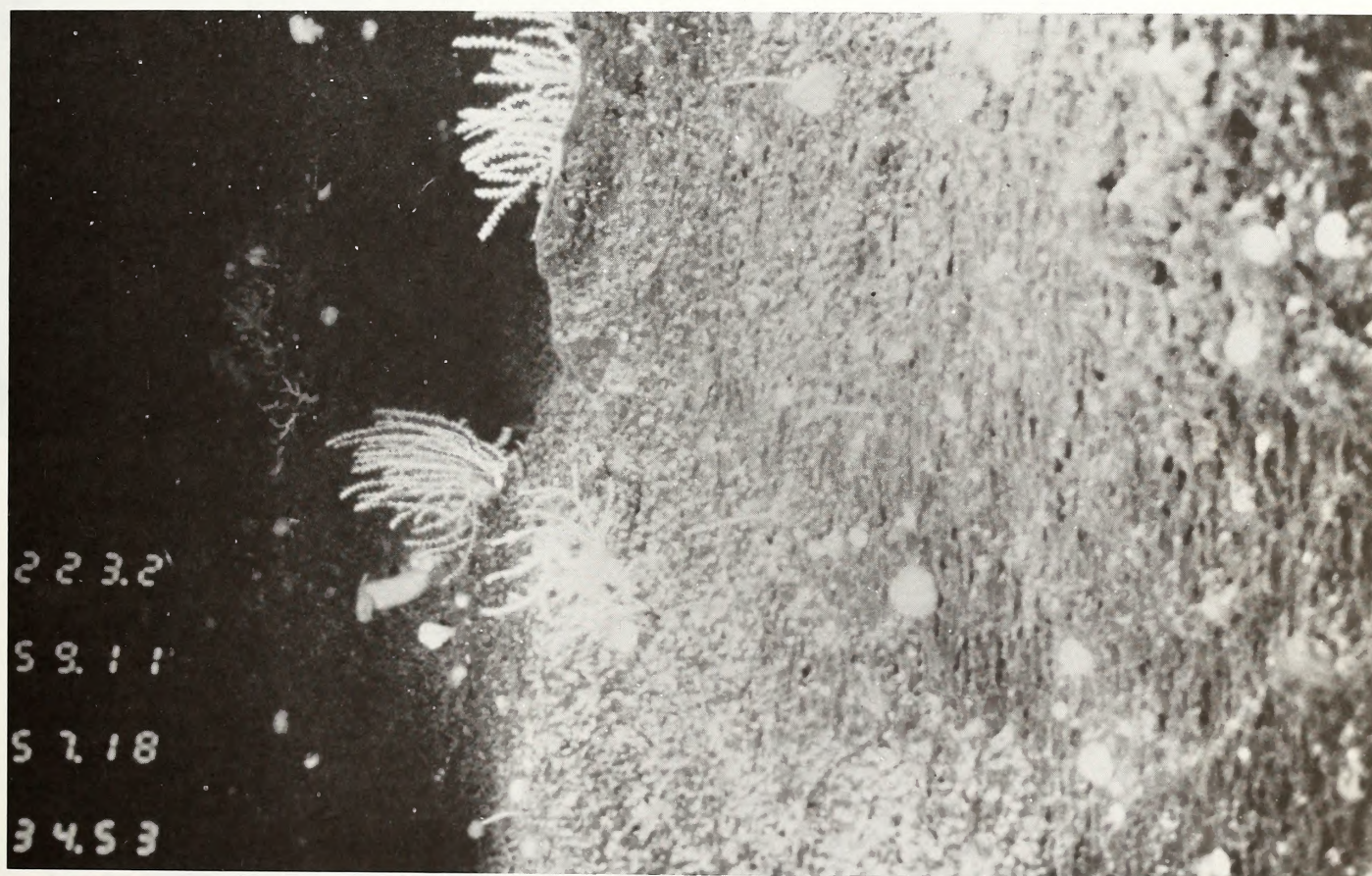


Figure 5. Photograph along a vertical face at dive site A. Height of cliff is about one meter.

In addition to the erosion by mechanical processes resulting from water currents, erosion by chemical and biological processes may be active. Because the solubility of calcium carbonate increases with increasing water depth, the lack of a pile of debris at the foot of the escarpment, suggested by seismic profiles, may be related to chemical corrosion, which would be enhanced by the high current speeds. The foot of the escarpment



Figure 6. Photograph showing jointed vertical outcrop. Width of photograph is about 2-3 meters.

(at 5 km depth) was below the diving capability of ALVIN. However, where we observed the cliff above 4 km, the rock fragments did not show rounded edges, as would be expected with chemical solution, but rather very angular corners, more consistent with a mechanical breakdown (Figure 6, 7, 8, 9, 10). Grooves, pits and borings in the rock face (Figure 11) may be caused by activity of modern organisms, particularly sponges, or they possibly might result from exhuming of burrows formed during sediment deposition and initially filled with less resistant sediment.

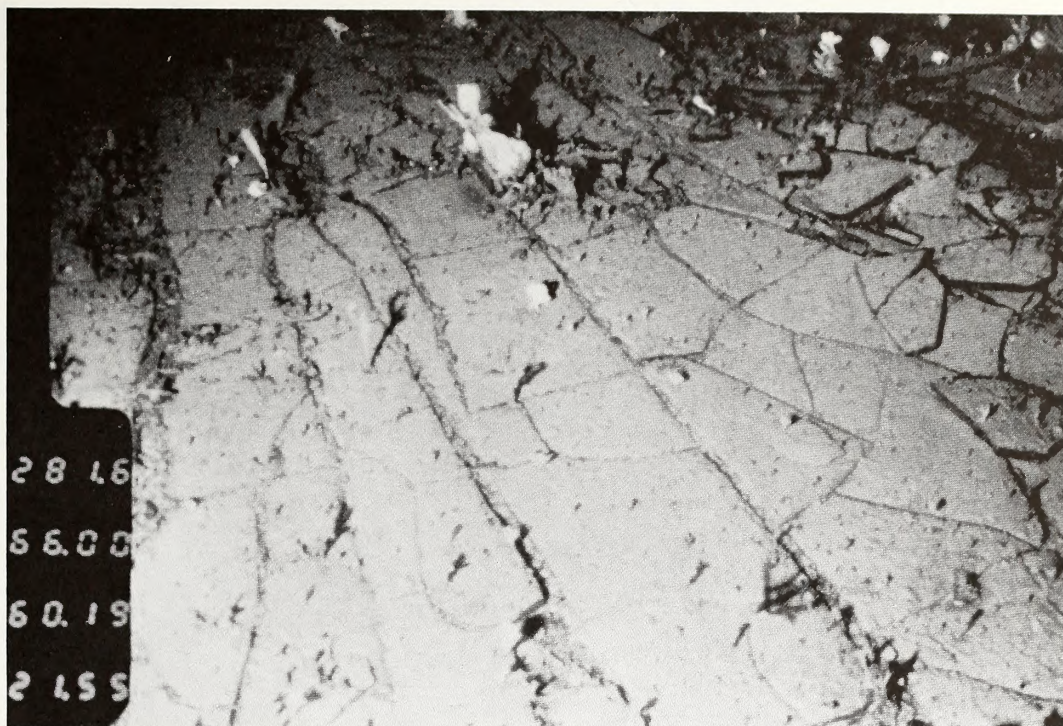


Figure 7. Photograph looking down on a horizontal stratum jointed into flagstones. Width of outcrop is about 2 meters.



Figure 8. Photograph along a stepped outcrop. Height of outcrop is about one meter.



Figure 9. Collapsed joint-bounded block about one meter in length. Note pteropod sand at bottom of photograph. Block is about one meter long.



Figure 10. Alternating layers of hard, lithified limestone coated with dark ferromanganese and light unlithified lime mud of the same age. The mud is relatively easily eroded. Photograph shows about one meter, vertically.



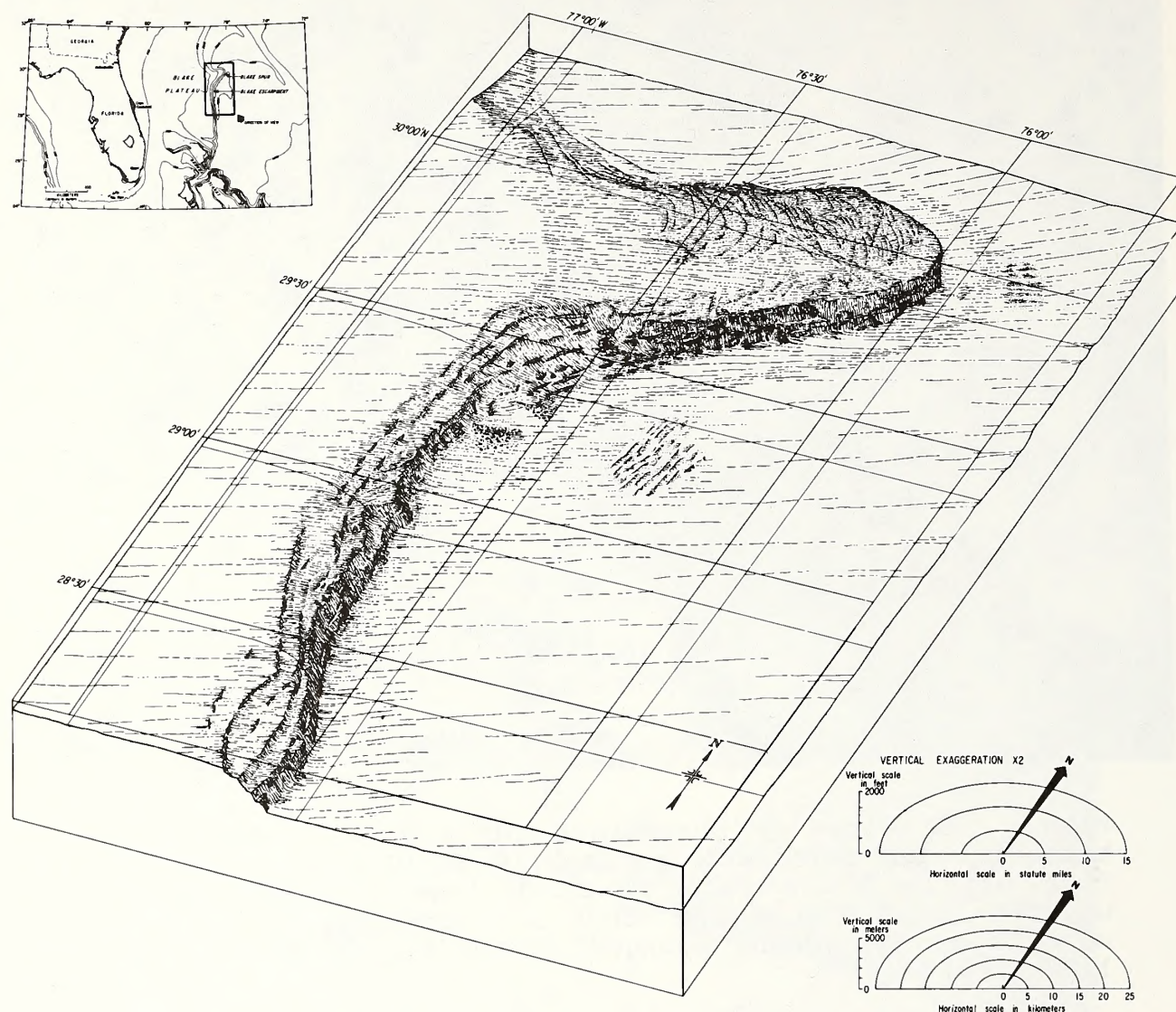
Figure 11. Close-up photograph of a small reentrant in cliff taken through observer's port while ALVIN was in contact with the face of the Blake Escarpment. Borings in rock and grooves in upper part of figure are about one centimeter in diameter. White objects are siliceous sponges. Width of photograph approximately 1/2 meter.

SUMMARY

By combining the echo-sounder, seismic profiling, and sidescan-sonar data with our observations from the submersible, we now have a very precise concept of the appearance of the Blake Escarpment. This represents a considerable advance in our knowledge of the nature of the sea floor and it has been summarized in a physiographic diagram (Figure 12).

Our initial hypothesis that the Blake Escarpment was formed by extensive erosional retreat of a submarine cliff face is strongly supported by observations and samples that were provided by submersible dives. Furthermore, these were results that only could be obtained by submersible operations.

Some of the evidence that supports the hypothesis of erosion and cliff retreat of the Blake Escarpment is summarized in Figure 13. Seismic data show the buried bench, the truncated strata at



Physiographic diagram of the Blake Escarpment
off Southeastern United States

by

Tau Rho Alpha, William P Dillan, Patricia Farrestel, Jeff Zwinakis
1981

Figure 12. Physiographic drawing of the Blake Escarpment. This is a presentation of the appearance of the escarpment on the basis of echo-sounder profiles, seismic-reflection profiles, a sidescan-sonar survey, and observations from a submersible. Diagram created by Tau Rho Alpha, Patricia Forrestel and Jeff Zwinakis.

the sea floor and escarpment, and the moat at the foot of the escarpment, and give some impression of the steepness of the cliff. Submersible work confirmed the steepness of the face and showed that it actually is much steeper than we had estimated.

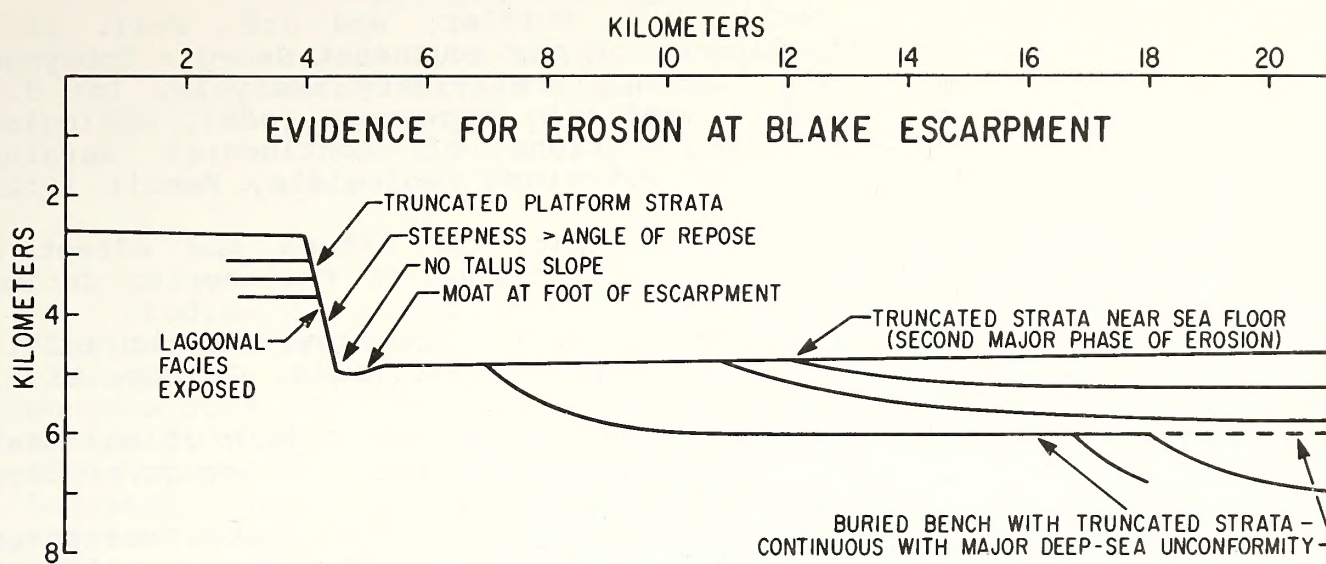


Figure 13. Summary of evidence for erosion of the Blake Escarpment.

Submersible sampling revealed the presence of rocks representative of deposition in the quiet interior of a carbonate bank. Perhaps most important, diving to the escarpment presented evidence on the processes of deep-sea erosion. We experienced currents much stronger than anticipated, observed modern biogenic sand which could provide the abrasive to erode rock, and saw the very extensive jointing that clearly is having a significant effect by fragmenting the rock. We have emphasized the role of physical erosion because evidence for that type seems to be the most obvious in the observations. Chemical corrosion of limestone, which becomes progressively more significant as depth increases, may be dominant below our range of observations. The blocky, angular nature of the rock fragments suggests that solution, which would tend to round the corners of blocks, is not dominant down to 4000 m depth. However, the steepness of the escarpment and moat at its base suggest that erosion may be concentrated at the base of the cliff, where chemical effects may become more significant. Obviously, we need to work at these depths, beyond the 4000 m operating limit of ALVIN.

Two major questions remain: (1) If erosion is more effective at greater depths, as it seems to be, how do the processes change with depth? (2) What are the relative importance of physical, chemical and biological erosion at all depths?

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BIOLOGICAL AND GEOLOGICAL PROCESSES AT THE SHELF EDGE
INVESTIGATED WITH SUBMERSIBLES

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ABSTRACT

Studies of living reefs along the shelf edge off eastern Florida and the Bahamas suggest the interrelation of physical, biological, and geological processes. JOHNSON-SEA-LINK submersibles were used to sample corals and sediment with a manipulator or by lock-out diving. Videotape and 35 mm cameras, CTD system, and transmissometer were used to document the dives. Sediment traps, light meters, time-lapse camera, thermographs, and current meters were deployed and recovered. A 222 km long reef system of discontinuous pinnacles capped with living and dead Oculina coral was studied off Florida. Upwelling may contribute to growth and community structure of the reef system. Growth rates of the coral averaged 1.6 cm/yr and the coral harbors diverse faunal assemblages. Each pinnacle produces carbonate sediment and traps mud sized particles. Sand and gravel particles are not transported far from the reefs. On the margin of Little Bahama Bank sediment traps were also deployed to study sediment transport through reef notches from shallow to deep water. Average sediment flux over the edge of the wall was 1.34 kg notch⁻¹ yr⁻¹.

INTRODUCTION

Within the last decade, the submersible has proved to be an invaluable research tool for the study of biological, geological, and physical processes on the continental shelf and slope, in midwater, and in the deep sea. These vehicles enable the investigator to observe directly and to sample discrete microhabitats; this is not possible with remote sampling from surface vessels.

Studies of living reefs along the shelf margin off eastern Florida and in the Bahamas suggest the interrelationships among physical, geological, and biological processes. This paper provides a summary of some of these studies on the shelf edge utilizing the JOHNSON-SEA-LINK submersibles.

MATERIALS AND METHODS

One study area was the Oculina coral banks at the shelf edge off central eastern Florida. This high latitude reef system consists of discontinuous prominences that are capped with living and dead colonies of the scleractinian Oculina varicosa Lesueur, 1820. Published data on these reefs which will be summarized herein consist of research concerning the structure and distribution of the Oculina banks, their associated fauna, the physical environment, and sedimentary processes. One particular

study site within this area was Jeff's Reef (27°32'N, 79°58'W), a 16-m high bank, approximately 1000 m in circumference, that has an extensive cover of contiguous, living coral.

Study areas in the Bahamas were at the shelf margin off Black Rock, Little Bahama Bank and San Salvador Island. Objectives at the Bahamian sites were to determine rates of sediment production by various biogenic sources, to identify sediment transport pathways, and to determine rates of sediment flux from the shelf to the slope.

The JOHNSON-SEA-LINK (J-S-L) I and II submersibles were used for sampling, deploying experiments and recorders, lockout diving, and photographic reconnaissance. These submersibles are capable of diving to 800 m for a duration of 3 to 5 hours and consist of 1.5-m diameter acrylic sphere, which carries a pilot and one scientist, and an aluminum dive chamber, which carries one scientist and a dive tender. The J-S-L's were fitted with some or all of the following equipment: two Benthos cameras (each with 30-m rolls of 35 mm film); 3/4 inch color video tape recorder with pan and tilt; manipulator arm with 19x19 cm clamshell grab, jaws and suction collecting tube; 12-bucket rotating sample basket; fish poison dispenser; conductivity-temperature-depth (CTD) recorder; transmissometer; current meter; and scanning sonar. Precision tracking of the submersible is presently plotted on the mother ship (R/V JOHNSON or R/V SEA DIVER) with a Honeywell digital acoustic positioning system and an Epsco plotter. Loran C and satellite navigation are used for ship positioning.

RESULTS AND DISCUSSION

Distribution of *Oculina* Banks

An initial determination of the distribution of the shelf-edge *Oculina* banks off eastern Florida was compiled from transcripts and film from over 135 submersible dives, 57 dredge and trawl records, and numerous echo-sounder and side-scan-sonar recordings (Avent et al., 1977; Reed, 1980; Thompson and Gilliland, 1980). This bank system roughly parallels the 70-80 m bathymetric contour from approximately 27°32'N to at least 28°59'N and possibly as far north as 30°. It consists of dozens and possibly hundreds of isolated prominences.

The prominences are steep-sloped (30-45°) structures, with maximum relief of 25 m and bases a few hundred meters in diameter. Numerous knolls with less than 5-m relief also occur in this region. Some of the prominences are covered with massive thickets of contiguous, living colonies of *Oculina varicosa* which grow 1-2 m in height. Maximum coral growth is usually on the south side of the prominences, facing into the Gulf Stream. Other prominences are covered completely with dead coral rubble or standing, dead colonies of *Oculina*. Prominences with all dead coral have been found within a few hundred meters of those with living coral, and the causes of death are unknown. Isolated colonies and thickets of living *Oculina* also occur on relatively flat sandy bottom among the prominences. A 92 nm² area of the *Oculina* bank system bounded by 27°30'N and 27°53'N has been designated as a protected habitat within the Coral and Coral Reefs Fishery Management Plan (Gulf of Mexico and South Atlantic Fishery

Management Councils, 1982).

Although echo-sounder records are useful to document the physiographic features of the shelf, and side-scan-sonar can detect hard bottom versus sand, neither technique can differentiate between living and dead Oculina. Thus it is necessary for direct observation with submersibles to determine the extent and distribution of the Oculina banks.

Physical Environment

A one to two year data base of near-bottom temperatures, currents, light levels, and sedimentation rates were collected at Jeff's Reef (80 m) with equipment deployed and recovered from the submersibles. The shelf-edge Oculina banks occur in a region of cold-water upwelling. Yoder et al. (1983) reported that upwelling occurred along the southeast U.S. 50% of the time from November to April. Our thermographs recorded a range of temperature from 7.4°C to 26.7°C and an average of 16.2°C (Reed, 1981). Cold water upwelled periodically from the Florida Straits with each event lasting 1-4 weeks and temperatures rapidly dropped below 10°C. During upwelling periods, levels of nitrates, phosphates and chlorophyll *a* increased by nearly an order of magnitude (R.M. Gibson, personal communication).

Although surface currents are usually strong and northerly from the Gulf Stream, the bottom currents have strong E-W, north, and south components (Hoskin et al., in press). Average near-bottom current speed was 8.6 cm sec⁻¹ but occasionally was in excess of 75 cm sec⁻¹ (Hoskin et al., 1983). Salinity was stable, ranging from 35.7 to 36.4 ppt (Reed, 1981).

Licor light meters recorded less than 1% of surface light at the 80-m reef. Most living Oculina on the banks lack zooxanthellae but some of this algae is present in the coral near the crest of the higher prominences. Turbid bottom water often inundates the Oculina banks reducing visibility to less than 1 m. This turbidity appears to be caused both by resuspension of shelf sediment and by plankton blooms resultant from the upwelling. Sedimentation rates averaged 53 mg cm⁻² day⁻¹ (Reed, 1981).

Ecological Studies

The Oculina biotope supports dense and diverse invertebrate and fish communities. A preliminary assessment of the macroinvertebrates (>0.5 mm) was made during a one year study in which 2-4 coral colonies (147-2715 g dry weight) were collected by scuba and lockout scientist-divers every 2-3 months at four reef sites (6, 27, 42 and 80 m). A total of 42 Oculina samples yielded over 20,000 individual invertebrates and were species-rich in mollusks (230 spp.), decapods (50 spp.), amphipods (47 spp.), echinoderms (21 spp.), and polychaete worms (23 families). Also common were nemertine and sipunculan worms, pycnogonids, tanaids, isopods, ostracods and copepods.

The shelf-edge Oculina (80 m) had a greater diversity of both decapods (Reed et al., 1982) and mollusks (Reed, 1983) than the inner and midshelf reef sites. The macroinvertebrate community composition and structure was distinctly different between the inner- and outer-shelf reef sites. Detritivores were the most abundant type of decapod at the shelf edge, whereas for the

inner and midshelf sites, mollusks, carnivores and coral-eating species dominated. Upwelling may provide an essential supply of nutrients and plankton to the shelf-edge Oculina community (Reed, 1983).

Other studies utilizing J-S-L submersibles on the Oculina banks resulted in descriptions of new species, subspecies, and in situ behavioral patterns of echinoderms (Miller and Pawson, 1979; Pawson et al., 1981; Pawson and Miller, 1983; Miller, 1984; Hendler and Miller, 1984a,b).

Dense populations of commercially and recreationally important fishes occur on the Oculina banks (Figure 1B). Over 70 species of fishes have been identified (R.S. Jones and R.G. Gilmore, personal communication, Marine Science Institute, University of Texas, Port Aransas, TX 78373) including scamp, gag, speckled hind, snowy grouper, black sea bass, porgies, and snappers.

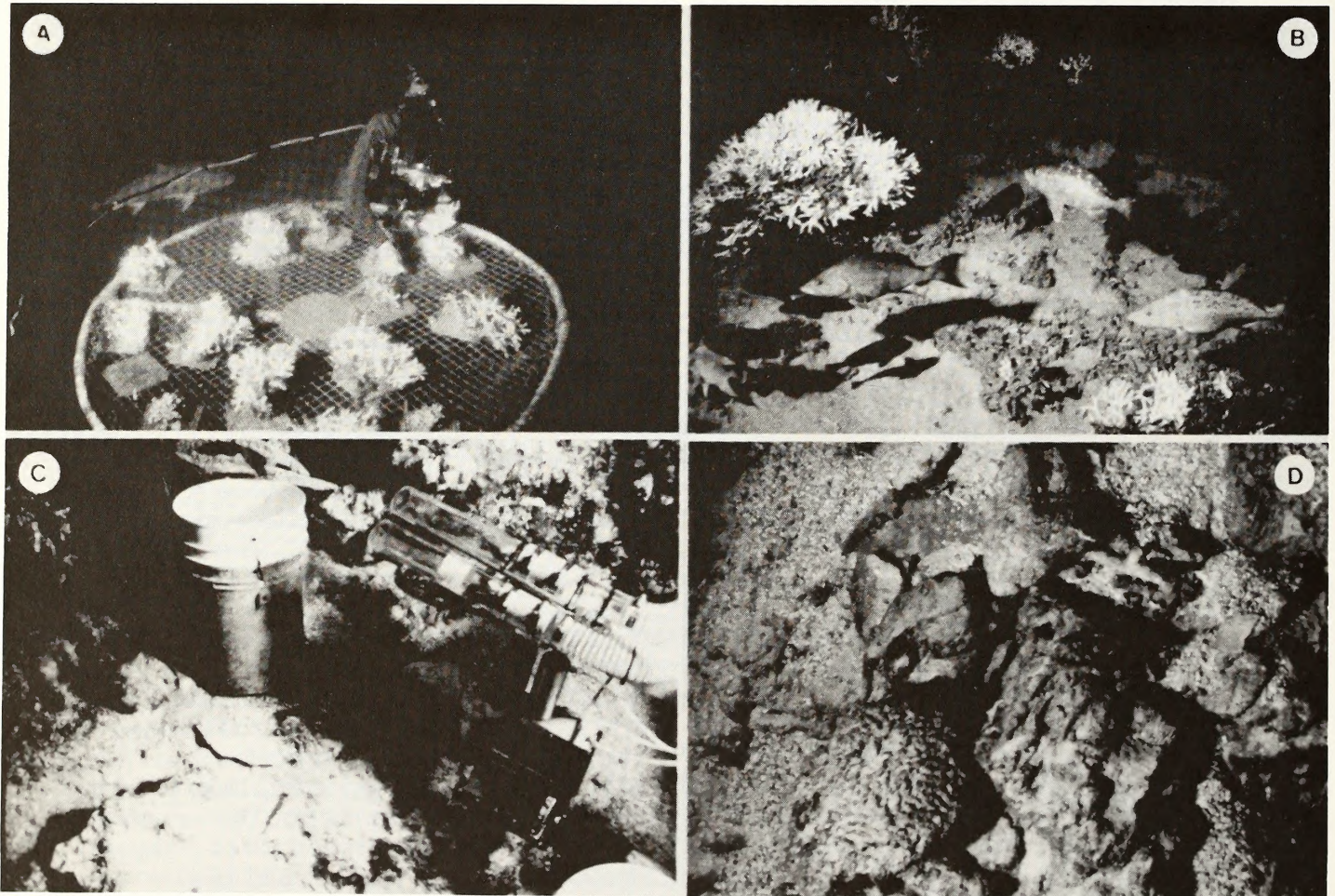


Figure 1. A) Lockout diver-scientist measures growth of Oculina coral at shelf-edge reef (80 m). B) Aggregation of fishes (scamp, snowy grouper, and drums) at base of Oculina reef (75 m). C) Sedimentation trap deployed with submersible's manipulator arm at base of wall (90 m) off Little Bahama Bank. D) Coral debris and Halimeda sand and gravel in groove of steep slope (464 m) off Little Bahama Bank.

Dense schools of anthiids (Hemanthias vivanus) congregate over and in the coral. Although H. vivanus is considered planktivorous, they have been observed (JKR) picking small food items from among the branches of Oculina. Schools of amberjack commonly travel among the banks. Spawning by the squid (Illex oxygonius) and mating by the roughtail stingray (Dasyatis centroura) have also been observed (Reed and Gilmore, 1981).

From submersible observations, grouper and snapper populations do not appear stable on any one reef but apparently travel among the banks and tend to prefer areas with living coral rather than dead coral rubble. Atkinson and Targett (1983) reported that greater fish densities were found on the outer shelf between Cape Canaveral, Florida, and Cape Hatteras, North Carolina, in zones of upwelling. The exact relationship and importance of the coral-associated invertebrate community to the fish community remains unknown. The influence of upwelling upon the entire Oculina bank system is also unknown.

Geological Processes - Oculina Banks

The substrate on which the Oculina banks have developed may be relict oolitic limestone ridges formed during the Holocene transgression (Macintyre and Milliman, 1970). The thickness of the coral rubble, sand and mud matrix which has built upon the rock base of the prominences is unknown. A lockout diver (JKR) was able to probe the sediment near the crest of Jeff's Reef with a 1/4 inch rod to a depth of 3.7 m without hitting bedrock. Rock outcrops are not visible on the majority of the prominences on which we have dived; however, rock pavement is often visible in small patches in the flat bottom surrounding the reefs. Rocks that we have collected from the base of several reefs consisted of oolitic, conquinoid, and pelletoid limestone. In addition, one sample collected at a reef base (88 m) was an Oculina biolithite, consisting of lithified coral rubble and mud.

Although we know from in situ measurements that the linear growth rate of Oculina branches averaged only 1.6 cm yr^{-1} at 80 m (Reed, 1981), the accretion rate of the banks is unknown (Figure 1A). One piece of Oculina rubble that was recovered from a depth of 8-12 cm in a short core taken by a lockout diver near the crest of Jeff's Reef was radiocarbon dated at $480 \pm 70 \text{ yr B.P.}$ (Hoskin et al., in press). Unfortunately, standard sub-bottom profiling is not suitable and deeper coring is not economically practical to determine the thickness of the coral and mud matrix on these prominences.

A detailed study was made of the surficial sediments at Jeff's Reef and the surrounding shelf and slope (Hoskin et al., in press). Non-reef samples were collected with a Smith-McIntyre grab from a surface vessel and the reef samples were collected with a clam-shell grab attached to the manipulator arm of the J-S-L submersible. The surficial reef sediments consisted of modern carbonate mixed with relict carbonate and quartz. There was more gravel in reef sediments (mean % = 23.8) than surrounding non-reef sediments (0.9-8.5%) and reef gravel consisted mostly of Oculina branches. Reef sand was mostly quartz (26.8%), mollusk shells (23.6%), foraminiferans (12.2%), barnacles (7.3%), and pellets (6.7%), along with carbonate rock fragments, echinoderm

fragments, coral, and coralline algae. In general, the reef sand contained significantly more barnacles and coral, and less ooids and pellets than surrounding non-reef sediments.

The reef sediment also contained a greater percentage of mud (14.3%) than nearby shelf sediments (4-8%). Some of this mud may be trapped by the reef from the water column through a baffling effect, and part is generated by microborers. Preliminary studies by the authors on bioerosion of Oculina indicate that attack is dominated by clionid sponges, 7 species of bivalves, eunicid polychaetes, sipunculans, and a boring cirriped. When weakened by bioerosion, the Oculina colonies become more susceptible to breakage by peak currents. In a tow-tank test, Oculina branches showed breakage at current speeds of 140 cm sec^{-1} (Hoskin et al., in press). The coral rubble is then subject to mechanical abrasion resulting in further production of gravel, sand, and mud size particles (Hoskin et al., 1983).

Shelf Margin Sediment Transport

Studies on the Oculina banks showed that currents may not be strong enough to transport coral gravel far from the reefs but export of coral sand is detectable (Hoskin et al., in press). These studies have not yet addressed whether the Oculina banks act as a barrier to the transport of sediment from the shelf to the slope as suggested by Emery (1968). However, transport of shelf sediment is part of several on-going studies in the Bahamas. Rates of erosion by chemical solution, physical abrasion, and bioerosion on the shelf have been measured by CMH. Bioerosion was found to be 20 times more intense than the other processes. One study showed that a population of 92×10^3 boring echinoderms (Echinometra lucunter) off Black Rock (400-m long) produced 9 tons of sediment per year; associated rock infauna produced an additional 6 tons yr^{-1} (Hoskin and Reed, 1985). The transport of the shelf sediment to deeper environments occurs by two main modes: 1) mud is transported in suspension over the shelf break, and 2) sediment moves through notches that cut through the shelf-edge reefs which otherwise act as barriers to sediment transport. This carbonate sediment is deposited in submarine aprons which is, recently, of interest to petroleum geologists.

We measured the rate of sediment transport over the shelf margin by deploying sediment traps with the submersibles in notches at the top of the shelf break (38-45 m), on ledges near the base of the vertical wall (80-90 m) (Figure 1C), and on inter-groove areas on the slope (464 m) (Hoskin et al., 1986). Initial results indicate that there is a decrease in sediment flux rates between the shelf margin and the base of the wall, indicating that some of the sediment is lost from surficial transport and is deposited as internal sediment. Average sediment flux through the bank margin was $1.34 \text{ kg notch}^{-1} \text{ yr}^{-1}$. The grooves on the deep slope contained much coarse grained sediment of shallow water origin, primarily Halimeda plates and also dead coral colonies up to 1 m diameter (Figure 1D). This downslope transport undoubtedly produced these grooves in the bedrock of the slope.

Future Studies

The above studies begin to unravel the complexities of the interrelationships among physical, geological, and biological processes. Physical factors such as current and wave surge are important for sedimentary processes such as bedload transport, sedimentation, abrasion, and breakage of coral. Other physical factors such as upwelling may be crucial for the maintenance of the shelf-edge Oculina banks and associated fauna by supplying nutrients and the concomitant plankton blooms. The physiographic features on the shelf-edge reefs affect sedimentary processes by trapping suspended sediment and damming sediment, which restricts transport off the shelf. The diversity of the faunal community at the shelf edge is also related to these geological features.

Some objectives for future submersible studies are:

- 1) What is the extent of the living versus dead Oculina reefs at Florida's shelf edge?
- 2) What agent(s) have caused the extensive areas of dead Oculina?
- 3) Is upwelling a major source of nutrients supporting the Oculina reefs and associated fauna, and what are the pathways of energy transfer?
- 4) What densities of commercially and recreationally important fish populations occur on the Oculina banks, and how are these fishes distributed in relation to live versus dead reefs?
- 5) Are the physiographic features of the Oculina banks primarily due to a buildup of coral debris and mud matrix or a result of antecedent rock structures capped with only a thin veneer of coral rubble and mud?
- 6) What are the pathways and processes of deep-sea apron formation at the margin of carbonate banks, and what is their potential as hydrocarbon reservoirs?

ACKNOWLEDGEMENTS

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CONTINENTAL SLOPE PROCESSES AND MORPHOLOGY

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ABSTRACT

Studies of geologic processes that shaped the Continental Slope offshore New Jersey are based on detailed bathymetric and geologic mapping, using conventional single-channel seismic-reflection profiles and core samples, followed by Sea-MARC sidescan-sonar surveys and observations from submersibles. Fine-grained sediments were deposited during the Pleistocene over eroded tertiary sediments and rocks. Turbidity currents left overbank deposits in the form of intercanyon ridges and, also canyon floors. Eocene rocks appear to have been continuously exposed on the lower slope since the Miocene, because deposition has been slight and episodic slides and debris flows have shed sediments to the upper rise. Less volumetrically important erosional processes probably include bioerosion, groundwater sapping, and solution of carbonates. Jointing has played an important role in structurally controlling topography of Tertiary outcrops by guiding mass wasting and other erosional processes.

INTRODUCTION

The nature and vigor of bottom processes are exceedingly important to well-conceived exploitation of offshore areas, and to oil and gas leasing in particular. In cooperation with the Bureau of Land Management, we investigated the geologic processes that act on the Continental Slope in an area about 45 x 45 km between Lindenkohl and Toms Canyons (Figure 1) (Robb et al., 1981a,b, 1982; Kirby et al., 1982; Hampson and Robb, 1984).

The area is crossed by several USGS multi-channel seismic lines (Grow et al., 1979). Eighty piston cores and several stratigraphic test wells provided ages and lithologies that we could use with our 900 x 1700 m grid of single-channel seismic-reflection profiles. We obtained nearly complete coverage of mid-range sidescan-sonar images using the Sea-MARC-1 system that belongs to the Lamont-Doherty Geological Observatory. The Sea-MARC 1 is a deeply-towed sidescan-sonar device that produces acoustic images of a 5-km wide swath of sea floor. Direct observations of the sea bottom were made during 14 dives in research submersibles.

This paper discusses the geologic background of a segment of the slope and the processes that formed the present surface. We point out that the landscape has resulted from many processes whose rates have varied with time, and that any description of those processes must be understood in terms of geologic history as well as present-day rates of activity.

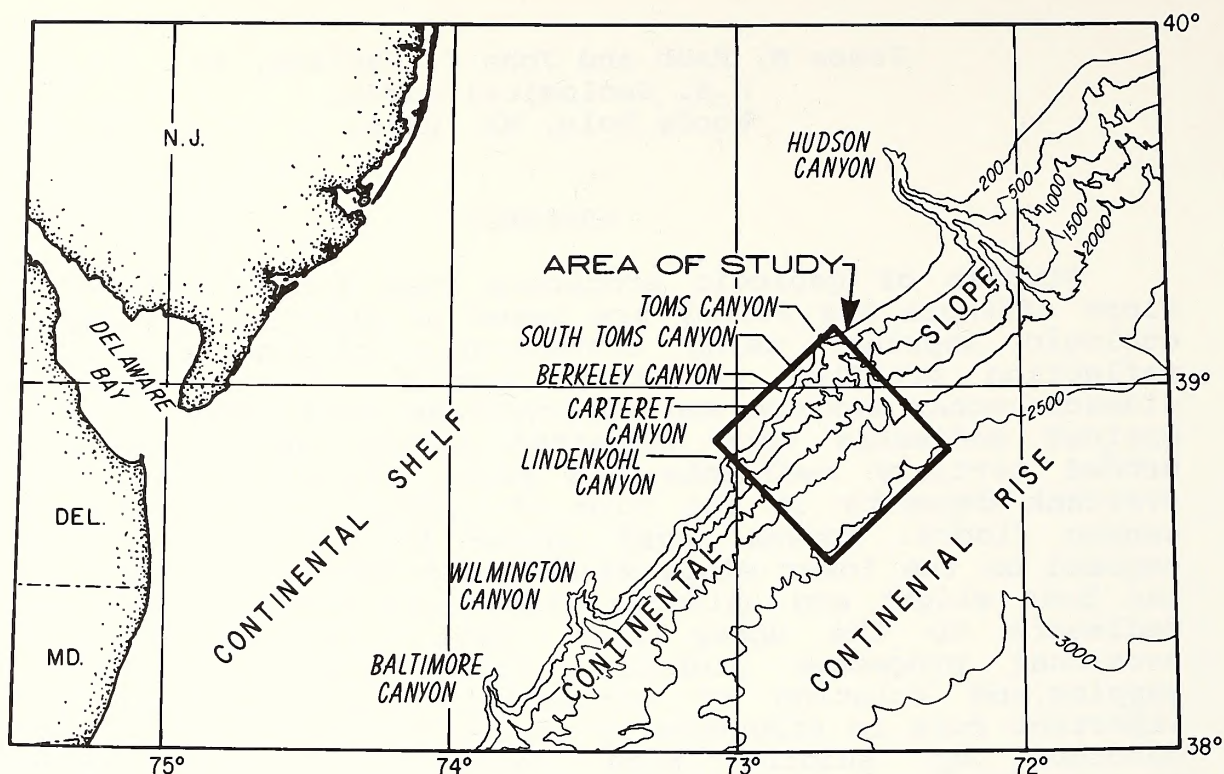


Figure 1. Location of study area on Continental Slope off New Jersey. Depths are in meters.

GEOLOGIC BACKGROUND

The continental shelfbreak in this area lies at about 140 m water depth. The transition between the Continental Slope and Continental Rise is near 2150 m (Figure 2). Between Lindenkohl and Carteret Canyons the slope surface is relatively smooth, but from Carteret Canyon to Toms Canyon, the slope surface is very complex, cut by Berkeley, South Toms, and Middle Toms Canyons. A number of canyons or valleys head on the Continental Slope, below the shelf break, and some, like Berkeley Canyon, do not extend to the Continental Rise. Relief on the rise is primarily in broad swales, in contrast to the canyons on the slope, but those swales do not necessarily link with features on the slope.

Profiles across the slope to the upper rise, show that slightly seaward dipping, sub-shelf Tertiary strata are truncated at the slope and covered by Pleistocene deposits (Figure 3). An area of exposed Eocene rocks on the lower slope represents the deep-sea unconformity A^u (Tucholke and Mountain, 1979). Eocene rocks, topped by the A^u unconformity, dip under the onlapping, later-Tertiary and Pleistocene sediments of the upper rise.

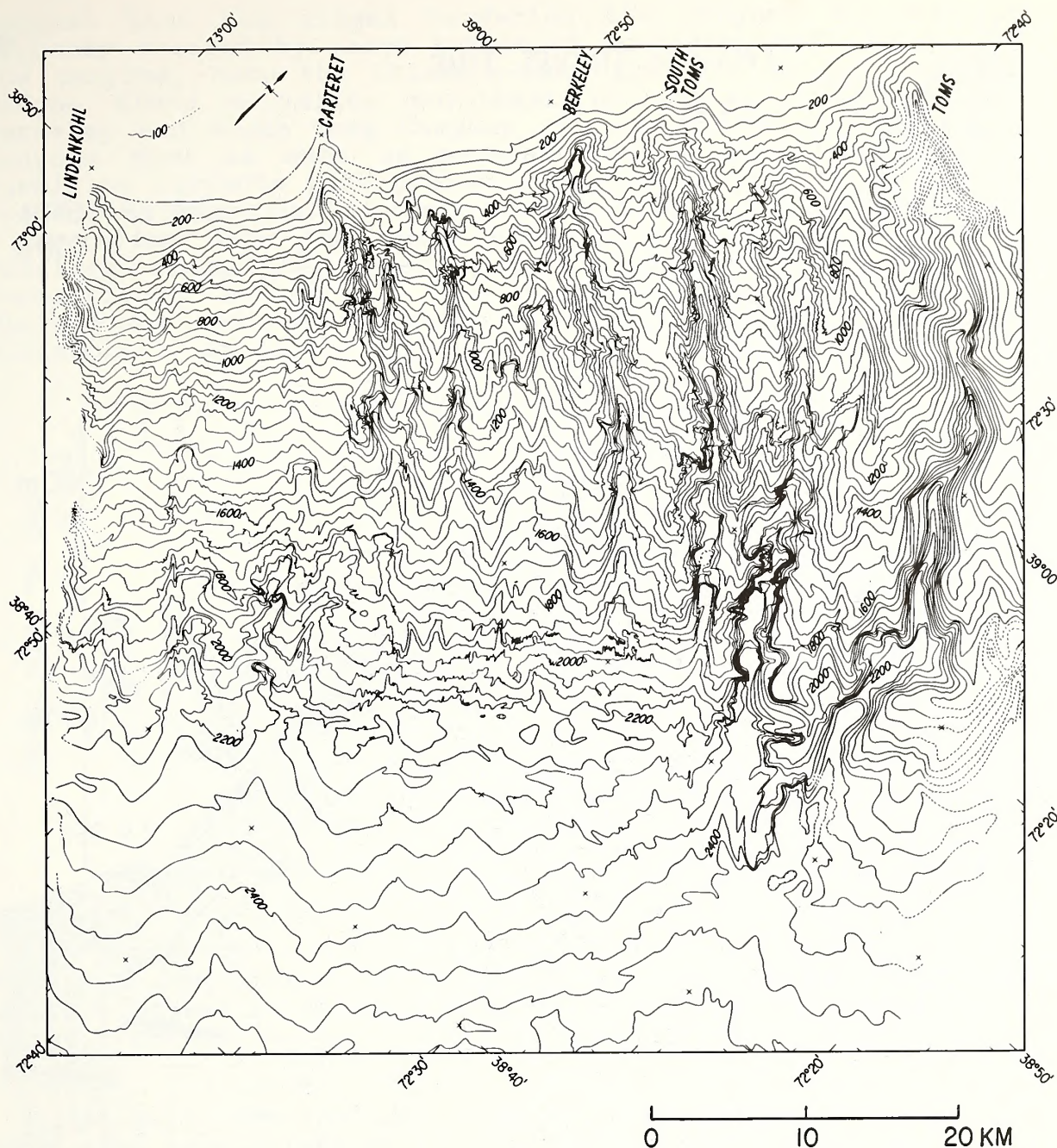


Figure 2. Bathymetric map. Contour interval 50 m.

Seismic profiles parallel to the contours near the middle of the slope show the topography of canyons, smaller valleys, and ridges (Figure 4), and demonstrate the sedimentary framework that creates the pattern of outcrops on the geologic map (Figure 5). Downslope-trending, mainly depositional, fingerlike ridges of Pleistocene sediments separate outcrops of Tertiary strata in the channel axes of the canyons and valleys.

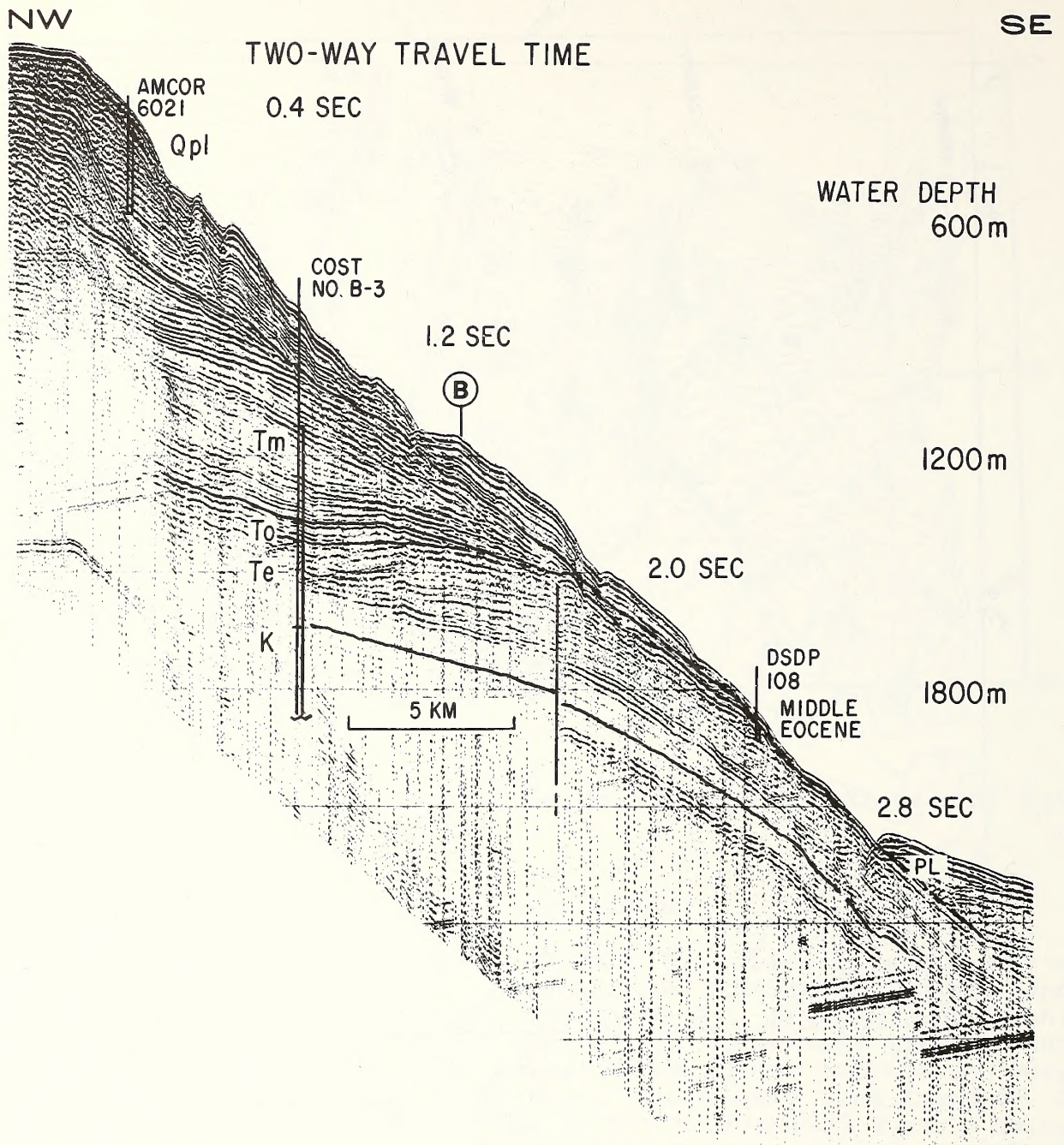


Figure 3. Single-channel seismic-reflection profile of the Continental Slope near Berkeley Canyon showing stratigraphic relations and well control. B shows where profile of Figure 4 crosses. Vertical exaggeration about 12:1.

OLDER HISTORY AND PROCESSES

Whereas the early Tertiary strata are generally planar, having been deposited on a surface of low relief, deposition since the late Miocene appears to have emphasized surficial irregularities rather than to have smoothed them (Figure 4). We

suggest that the ridges bordering the canyons may be levees, probably created by large turbidity currents that spilled out of the canyons. Note the thinning-away from the canyon axes of the ridges along a valley northeast of Carteret Canyon, and at Berkeley and South Toms Canyons (Figure 4). In some places these canyons show as much as several hundred meters relief. Large turbidity currents were probably created by storms and waves that eroded and suspended fine-grained, glacially derived sediments at a shoreline near the shelf edge during low sea-level stands. Profiles along the lower slope (Figure 6) show clearly the depositional nature of the canyon-bordering ridges in that Pleistocene sediment is deposited locally over a nearly planar unconformity on Eocene strata.

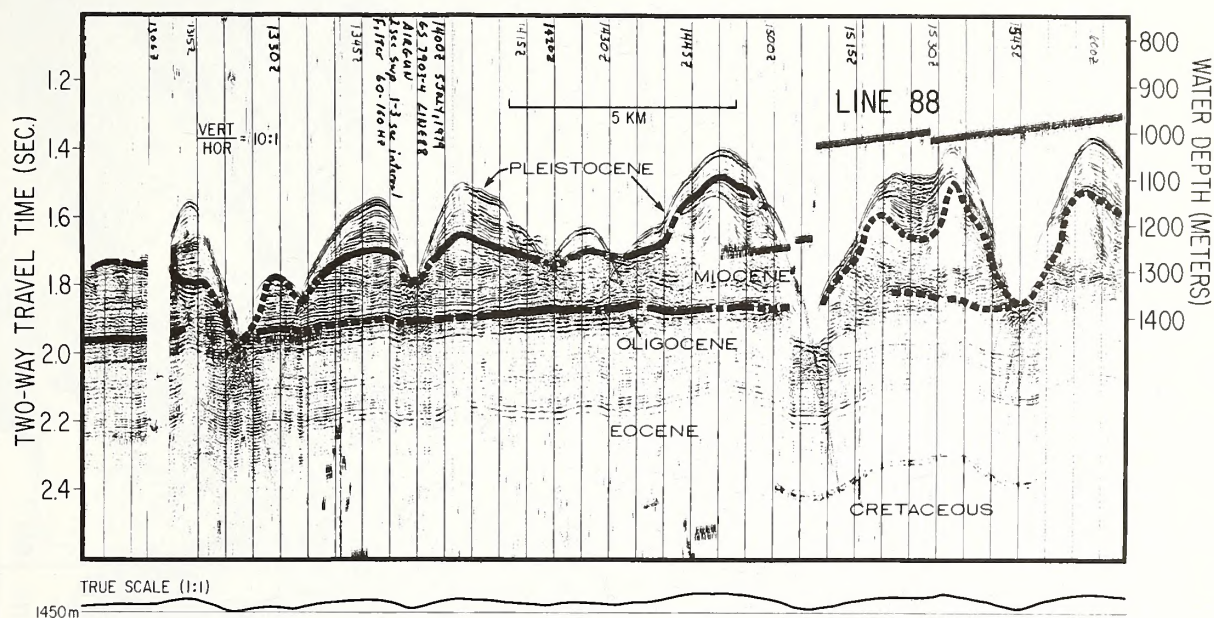


Figure 4. Seismic profile along the continental slope showing shallow structure beneath present topography. SW to left, NE to right. The two canyons to the NE are Berkeley and South Toms.

Seismic profiles across deeper, steeper places in the canyon axes show truncations of once continuous beds; erosional deepening has also taken place. Areally, there were several periods of canyon cutting. Profiles along the upper slope between Lindenkohl and Carteret Canyons show a number of buried valleys within Miocene strata. Several filled and partially reexcavated canyons also are present in the Pleistocene sediments of the upper slope along the northeast sides of present canyons.

On the lower slope, less erosional deepening of canyons occurred. However, there are great differences in the history or stage of development of individual canyons. For example, whereas Berkeley Canyon shows little erosional incision, Carteret shows more, and South Toms Canyon is deeply excavated (Figure 6).

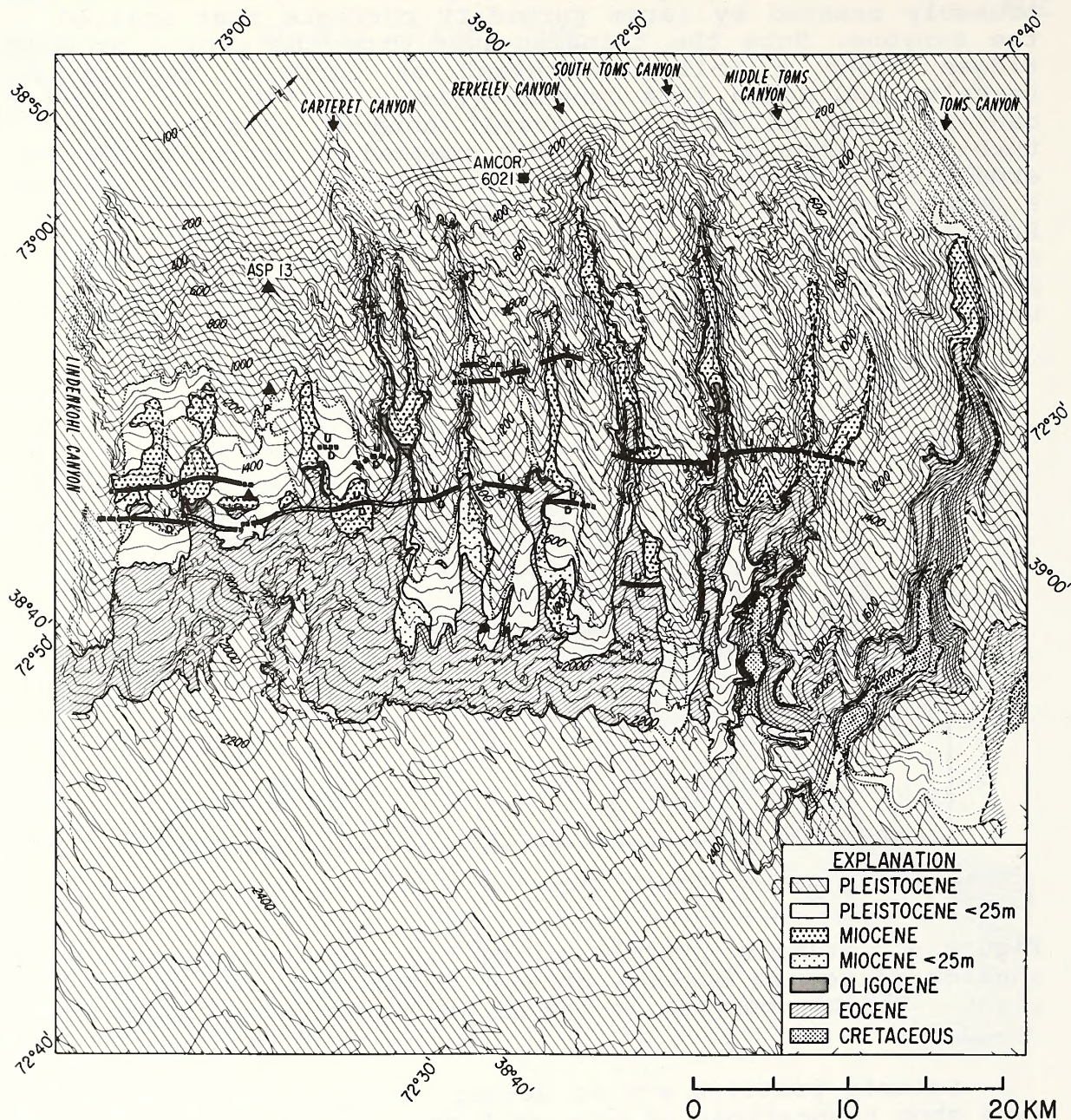


Figure 5. Geological map. Contour interval 50 m.

Excavation of channels also took place in the deep water of the uppermost rise, creating the relief on the A^u unconformity (Figure 7). The topography on that unconformity is probably of Oligocene or early Miocene age. Buried valleys there are similar in size to channels of the larger present-day canyons where they cross the rise. The buried valleys are not expressed in the present-day bathymetric surface. One of the buried channels was drilled by the Deep Sea Drilling Project (DSDP) hole 604, and clasts of Eocene rocks in a matrix of Miocene-aged fill were

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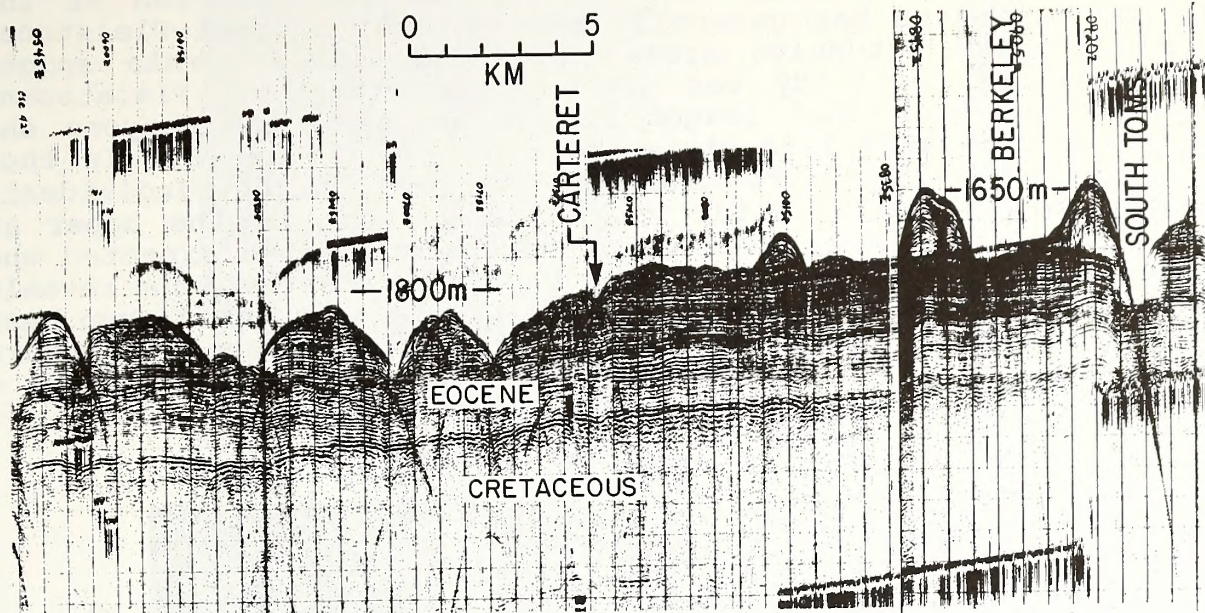


Figure 6. Seismic profile along lower slope.

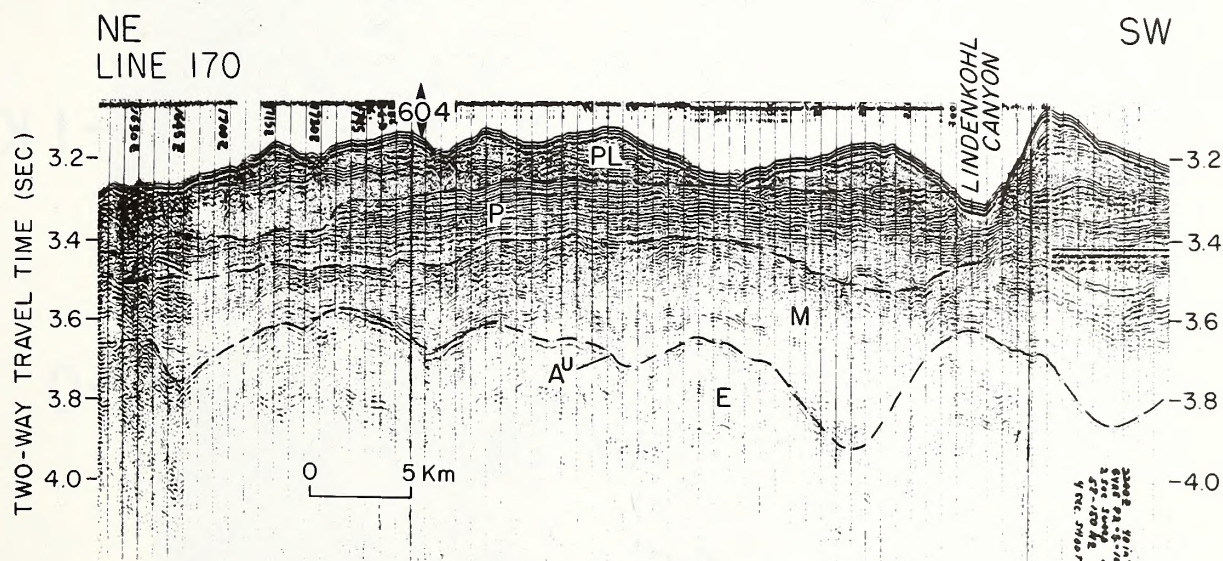


Figure 7. Seismic profile along upper Continental Rise. PL = Pleistocene, P = Pliocene, M = Miocene, E = Eocene.

recovered (C.W. Poag, pers. commun., 1983), showing that Eocene rocks have been exposed for a long time on the lower slope.

SURFICIAL EROSIONAL FEATURES

The present surface of the Continental Slope is covered nearly everywhere by as much as several meters of fine-grained

sediment which has been dated to be as old as 30,000 ybp (Prior et al., 1984). Consequently, it is inferred that erosion of this part of the slope has generally been minimal in post-Pleistocene time, although extensive erosion of Pleistocene strata suggest that erosional activity was great during the late Pleistocene. Sea-MARC sidescan-sonar images of the heads of the canyons show traces of truncated late-Pleistocene strata (Figure 8). In those areas, erosion appears to have acted in small bites. Individually identifiable slump or slide scars are present on the upper and middle slope, but they are not as common as we had expected when we began this mapping project. Submersible observations revealed meter-sized slumped blocks from place to place in the canyon heads (Slater et al., 1981). One probable slide scar several hundred meters long on the side of a small valley on the upper slope at about 900 m water depth is shown in Figure 9.

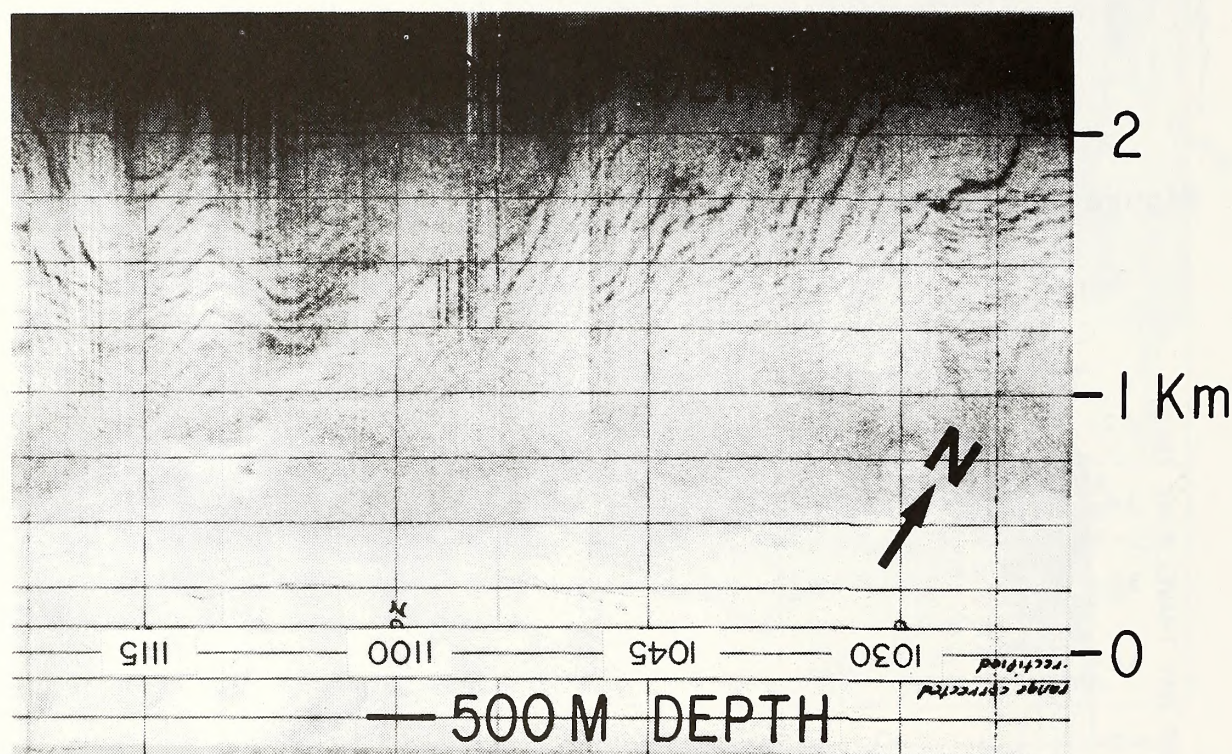


Figure 8. Sea-MARC sidescan-sonar image of truncations of Pleistocene strata near head of Berkeley Canyon. The sidescan-sonar images in this paper display darkness in areas of returned echoes. Areas where echoes were not received, usually because they lie in an acoustic shadow, are white. In this image, the sidescan fish was towed horizontally across the photograph at the level of the zero on the distance scale. Sound was projected in an upslope direction, toward the upper part of the image, and the downhill-facing scarplets caused by differential erosion of the Pleistocene strata reflected the acoustic signal more strongly than their surroundings.

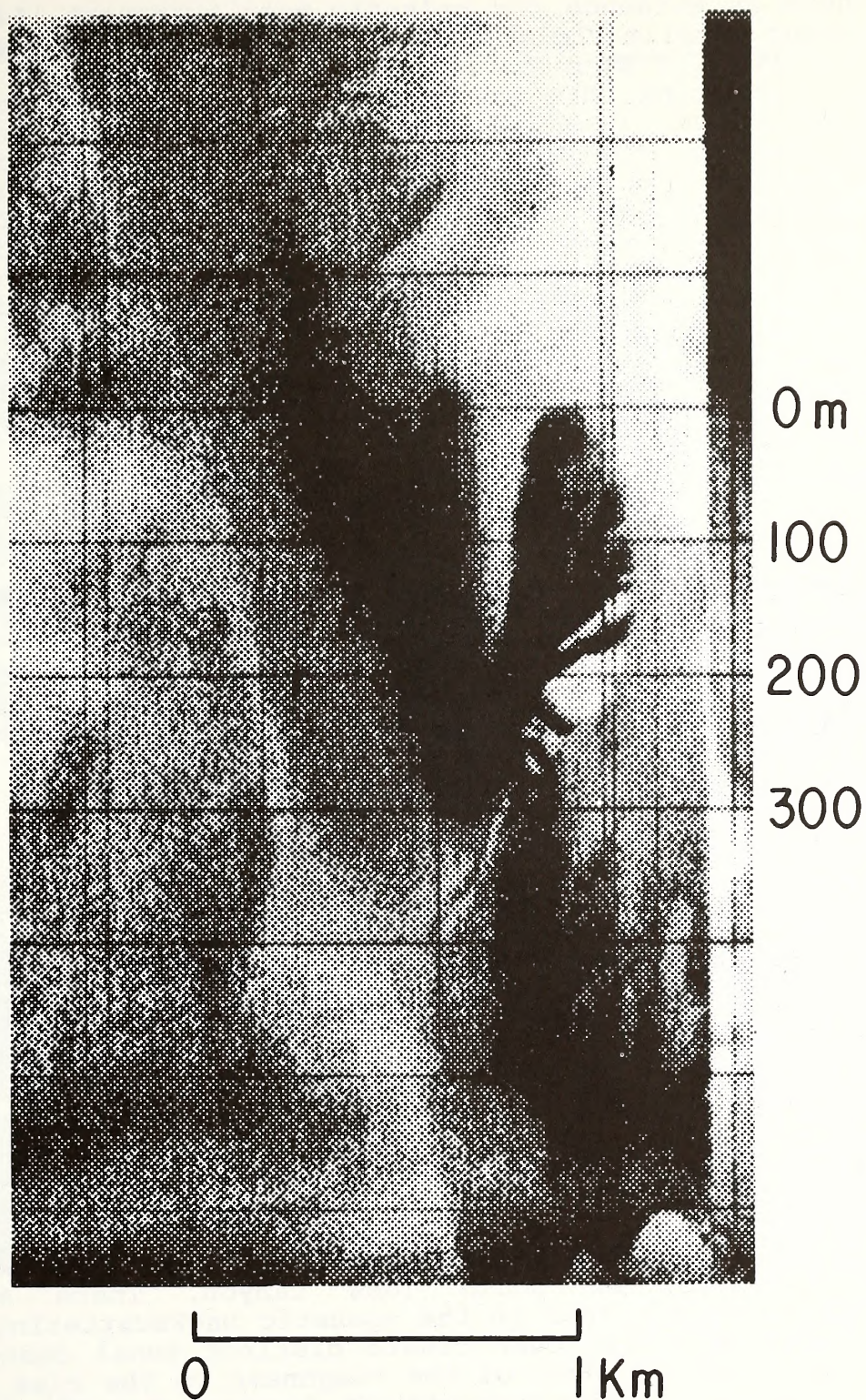


Figure 9. Sidescan-sonar image of small slide on upper Continental Slope in Pleistocene deposits. Water depth about 900 m. Fish location for this image is similar to Figure 8. Upslope is to the upper left. The wall of a small valley that runs from upper left to lower right is cut by a slide scar.

There is evidence for episodic mass transport. Linear mounds of sediment overlie Pleistocene sediments along the present slope-rise boundary. Piston cores show Eocene clasts in Pleistocene matrix, suggesting that the mounds are debris-flow deposits from the lower slope. Profiles show similar structure in strata as old as Miocene. Sea-MARC images show a debris deposit on the upper rise at the mouth of South Toms canyon (Figure 10), and observations of the area from Alvin show clasts of Eocene rocks like those that crop out on the lower slope. This material probably originated in a rockfall within the canyon and was transported to the rise by debris flow. We observed places in other canyons or valleys of the lower slope where cliffs showed fissures along their rimrocks that portend future rockfalls. Our sidescan-sonar coverage of South Toms Canyon is incomplete, and we do not know the site from which this particular material came or when the event occurred.

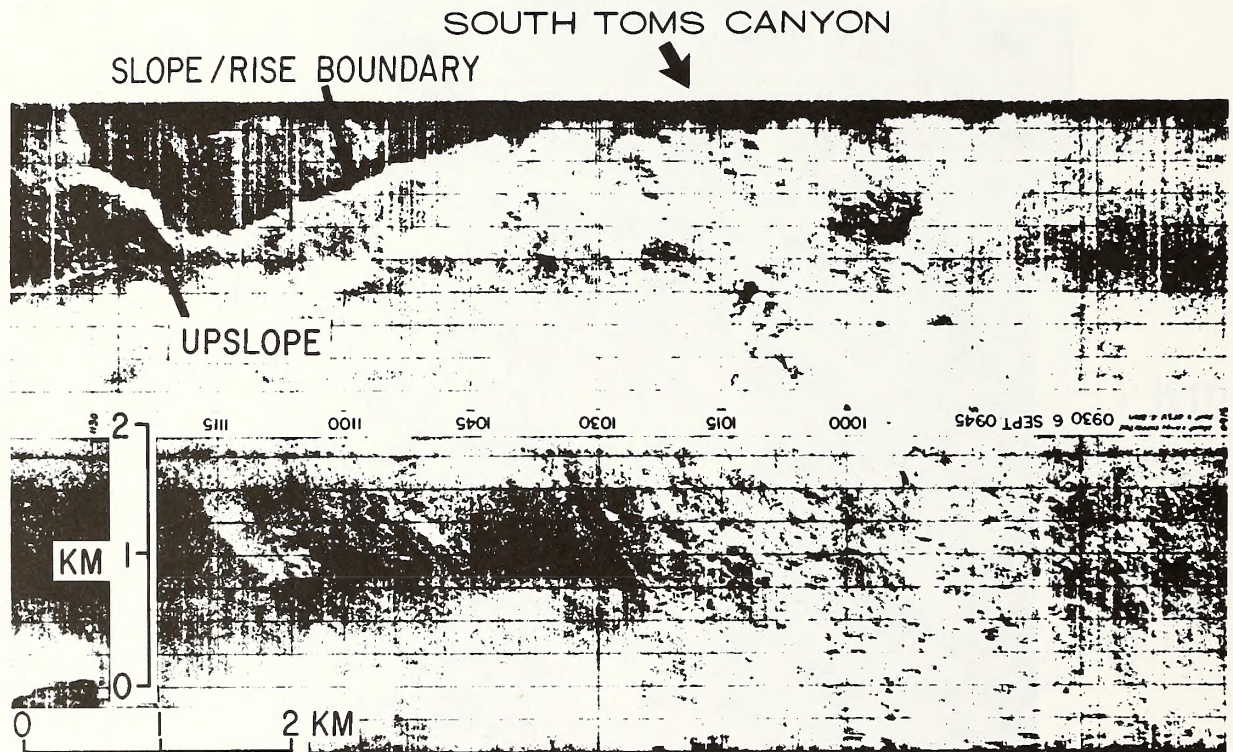


Figure 10. Sidescan-sonar image of debris on upper Continental Rise near mouth of South Toms Canyon. There are marked differences in this area in the acoustic backscattering qualities of the slope and rise that create distinct tonal changes at the slope/rise boundary. Much of the roughness on the rise shown here is caused by meter-sized blocks of Eocene rocks deposited by a debris flow or rockslide.

Steep-walled basins (Figure 11) are found in a number of valleys that cut the lower slope and in the lower reaches of Carteret Canyon. Some resemble slump scars; others are terraced

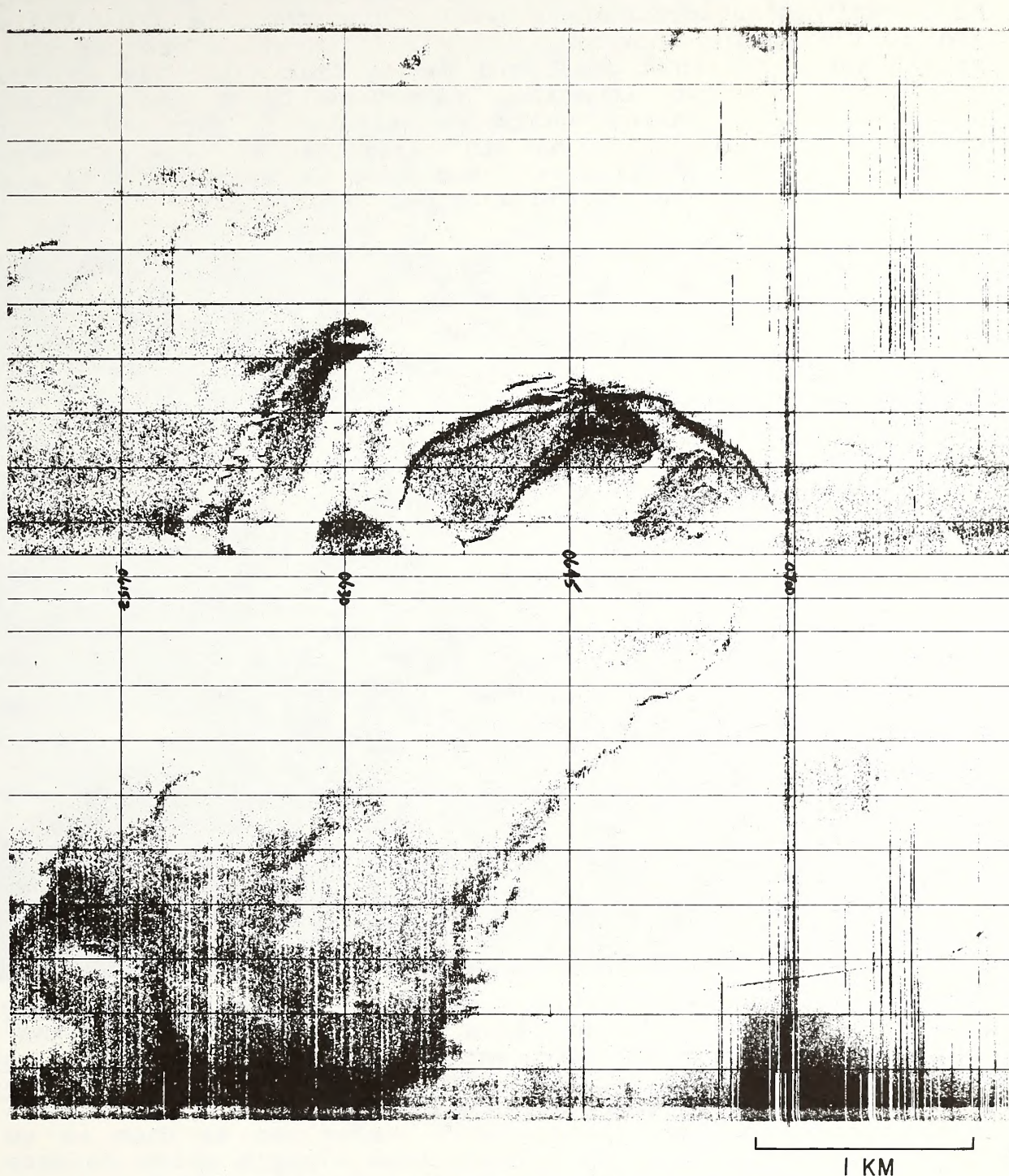


Figure 11. Valley basin on lower Continental Slope. Water depth about 2000 m. Sidescan fish was towed across the middle of this image. Upslope to upper right. Note shape of valley, and terraces at bedding surfaces. Smaller basin at left.

and appear to have been eroded along bedding planes in consolidated chalks and mudstones. The basins are found along the

slope, from valley to valley, in places that appear to correspond to certain stratigraphic intervals. Observations from Alvin in two of the basins show that their cliffed walls are undercut in many places, and that cliff and valley orientation is controlled by joints. In two locations sandstone dikes were observed, projecting from valley walls or floors (Figure 12). Arched recesses were also observed in cliff faces. Several recesses expose 8- to 10-cm diameter tubes that we believe to be fossil burrows of Miocene cerianthid anemones (Figure 13).

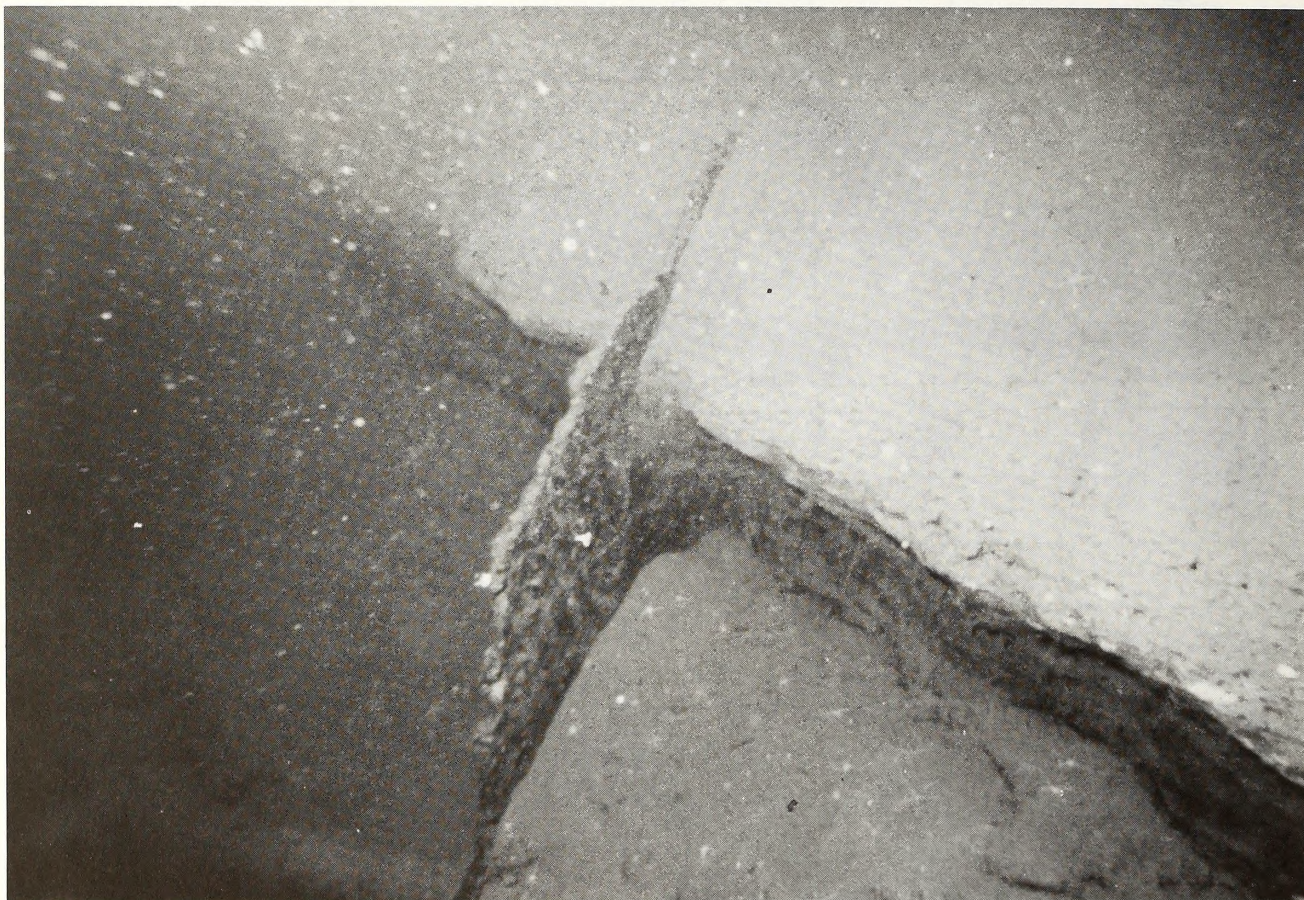


Figure 12. Sandstone dike in a cliff-walled valley observed from Alvin. Image spans about 5 m. Water depth about 1500 m. Fragile, easily broken dike and abrupt, clean projection from cliff on both sides implies lack of landslide and some other process than current erosion for wall retreat.

It has been suggested (Robb et al., 1982b; Robb, 1984) that these steep-walled valley basins may have been created by what Douglas Johnson (1939), in an early paper on the origin of submarine canyons, called artesian spring sapping. Excess pore pressure could result from the differential head between now-subaerial parts of the Coastal Plain and the sediment below the Continental Shelf and Slope during periods of low sea level. The concept is supported by digital hydrologic modelling, using modern



Figure 13. Alcove in valley wall observed from Alvin. Cylindrical features (about 10 cm in diameter) are believed to be fossilized tubes of Miocene cerianthid anemones. Tubes are fragile. Erosion has been slow, localized, and not by landslide. Water depth about 1500 m. Similar appearing alcoves in Colorado Plateau area are attributed to groundwater sapping along bedding planes.

seismic-reflection profiles and permeability data from the Continental Offshore Stratigraphic Test (COST) well B-2 on the Continental Shelf (Leahy and Meisler, 1982).

Steep-headed basins having undercut walls are characteristic of spring-sapped features (Higgins, 1982). The sandstone dikes observed from Alvin are fragile, and protrude from the cliff face by as much as one meter (Figure 12). One such dike was easily sampled using Alvin's manipulator. Its preservation implies slow erosion of that cliff face, consistent with erosion by groundwater discharge, but inconsistent with mass movement. Similarly, the arched recesses with exposed, fragile trace fossil simply slow, particle by particle erosion (Figure 13). Arched recesses in canyons in the southwestern United States are attributed to groundwater seepage (Robinson, 1970).

Another process that may have acted on the lower slope is solution of calcareous rocks and cements. Should fresh

groundwater be discharged into seawater, a mixture is created that is more corrosive than either of the components. Bays on the coast of Yucatan, for example, are attributed to rapid erosion by discharging groundwater mixing with seawater (Hanshaw and Back, 1980). Reticulate linear depressions in the lower slope resemble fissures along joints that are a common karst phenomenon (Figure 14). Although specific reticulate linear depressions were not directly observed from a submersible, we did observe gaping fissures along joints elsewhere in cliff faces.

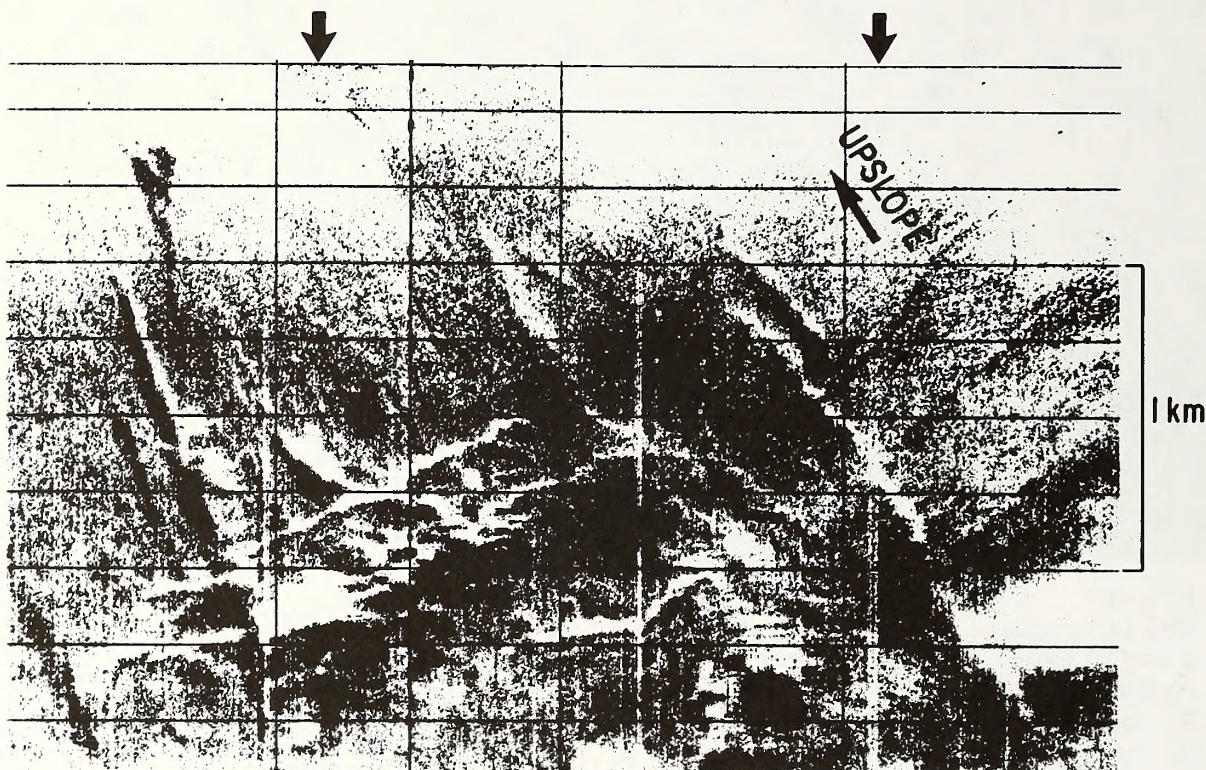


Figure 14. Sidescan-sonar image of reticulate sea-floor fissures located near Berkeley Canyon. Water depth about 1700 m. Probably Miocene terrain. Arrows at the top of this image show the direction of sidescan view. Here, the sidescan fish was towed along the top of the photograph, and linear fissures appear as white shadowed areas.

There are features of the faces of outcrops that may also be products of solution. Figure 15 shows some small depressions that look like solution pits along the near-horizontal outcrop of a bedding plane. We speculate that the vertical grooves above those pits may be analogous to rill lapies, or rillenkarren, karst features thought to be formed by rainwater running down an outcrop. If freshwater were expelled along a bedding plane, would it rise through the denser seawater and create an "upside-down" lapies pattern?

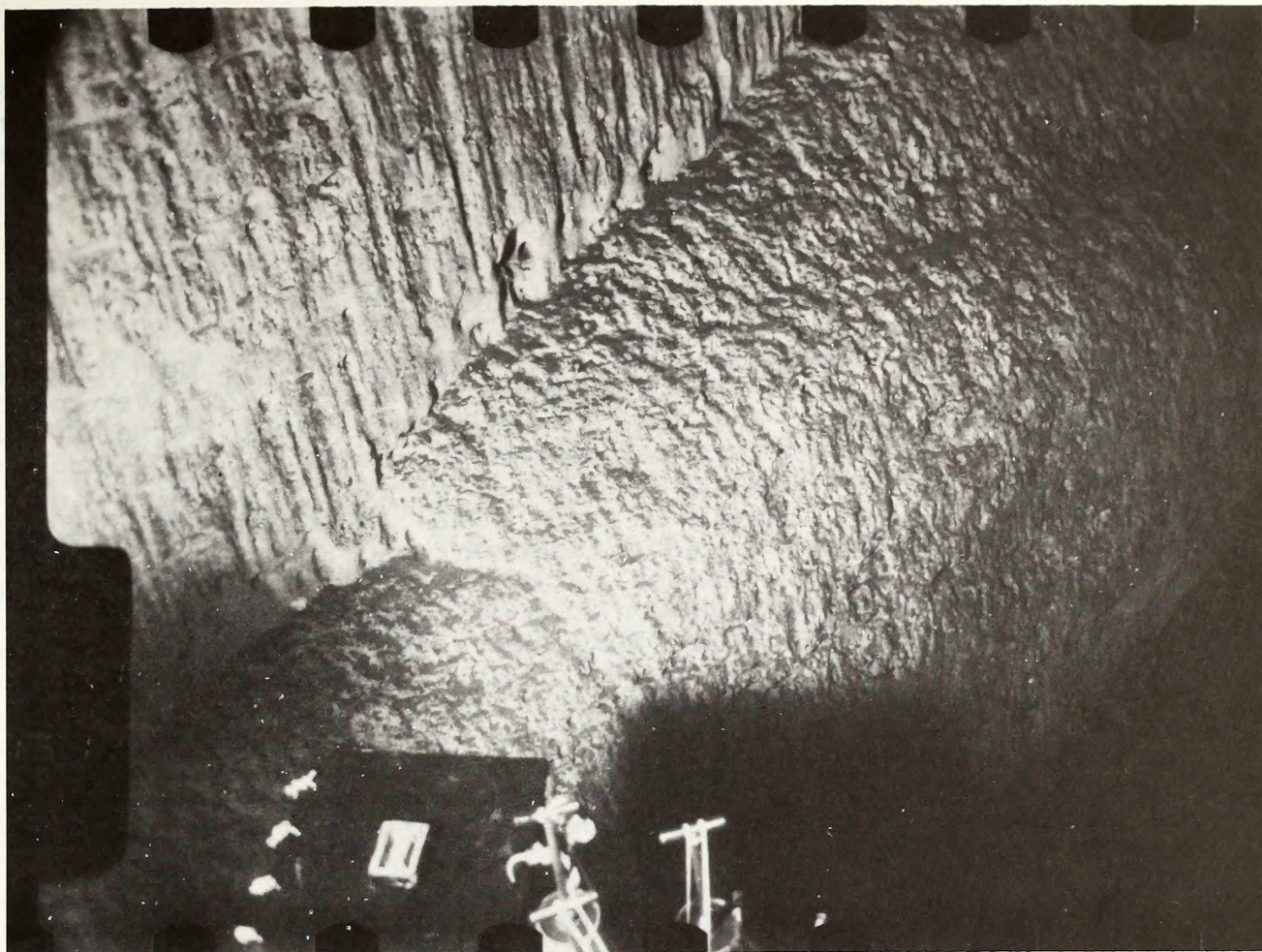


Figure 15. Outcrop observed from Alvin in lower slope valley. Note solution pits (?) along bedding plane, and rilled surface. See text. Image spans about 3 m. Water depth about 2000 m.

SUMMARY

On the Continental Slope, deposition and erosion have operated at different rates in different times and in different places on the slope. Much of the present surface is old. The upper slope topography, including the canyons, is cut in late Pleistocene deposits. Intercanyon ridges on the middle slope are of Pleistocene age, and result primarily from deposition on a pre-Pleistocene erosional surface, although some of the larger ridges were initiated during the late Miocene. The lower slope features, of smaller dimensions, are primarily erosional, and were created by many processes over a long time. Overall, the present geomorphic picture is of deposition sculpted by erosion, and finally covered by thin recent sediment. Because there is evidence of geologically recent slides or rockfalls whose historic age is not known, in a terrain having steep slopes and cliffed outcrops, common prudence would dictate caution and pre-placement investigation for any engineering effort.

ACKNOWLEDGEMENTS

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SEDIMENT TEXTURE AND DYNAMICS OF OUTER SHELF AND
UPPER SLOPE DEPTHS ON THE SOUTHERN FLANK OF GEORGES BANK

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ABSTRACT

Observations from submersible dives on the outer shelf, in the head of Oceanographer Canyon, and on the nearby gullied upper slope indicate that sediment dynamics differ markedly in adjacent areas at the same water depth (150-650 m) on the southern flank of Georges Bank. Sediment types in Oceanographer Canyon are immobile gravel on the rim, firm bioeroded silt exposed on the lower walls, and rippled and duned medium to coarse sand on the walls and floor. Upper slope sediment is unrippled, finer grained sand. Shelf currents transport sand onto both the canyon wall and upper slope; contrasts in the texture of the mobile sediment in the two areas are directly related to the strength and orientation of bottom currents. Current observations are based on results of long-term deployments of current meters by other workers, and on in situ observations from submersibles. Along-shelf currents of unknown origin flow westward across the canyon rim. Strong north-south tidal currents dominate flow up and down the canyon axis to at least 630 m, and their strength is related to canyon size and shape. In contrast, tidal currents on the upper slope are weak, but strong currents related to Gulf Stream eddies flow eastward along the slope above 300 m. Major sea floor processes in the energetic canyon head are erosion and transport out of the canyon of fine-grained sediment accompanied by accumulation of shelf sand on the canyon floor; whereas deposition of fine sediment as well as sand is more likely to occur in the same depth interval on the more tranquil upper slope.

INTRODUCTION

Recent investigations of the geology and biology on the southern flank of Georges Bank in the vicinity of Oceanographer and Lydonia Canyons have focused on sediment texture and transport, the distribution of sediment types, and the description of the faunal assemblages and habitats (Valentine et al., 1980, 1984a,b; Twichell, 1983; Cooper et al., in press). During the same period, hydrodynamic studies have identified the major current patterns in the region (Keller and Shepard, 1978; Butman et al., 1982, 1983, in press; Butman and Beardsley, in press). In particular, the Lydonia Canyon hydrodynamic experiment done by Butman and his colleagues has contributed greatly to the explanation of sediment transport patterns that previously had been inferred from textural analyses, from sedimentary features, and from a few observations of current speed and direction made from submersibles.

The outer shelf and upper slope is a transitional sedimentary province characterized by an increase in the steepness of the sea

floor. The study areas (Figure 1) exhibit a wide variation in sedimentary environments that are related to sea floor morphology, to sediment sources and to current patterns. In water depths between 150 and 650 m, a relatively smooth, seaward-facing outer shelf and upper slope, oriented approximately east-west, is incised at about 350 m by narrow, steep-walled gullies that extend far downslope (Figures 2 and 3b). By contrast, in the same depth interval, the shelf edge is incised by canyons of varying size that are oriented approximately north-south.

Georges Bank is isolated from continental sediment sources by the Gulf of Maine. On the southern flank of the bank, bottom sediment varies in texture from cobble and boulder gravel pavement on the canyon rims to silty sand on the upper slope. Excluding the presently immobile cobbles and boulders and the extensive deposits of bioeroded, semiconsolidated Pleistocene silt exposed

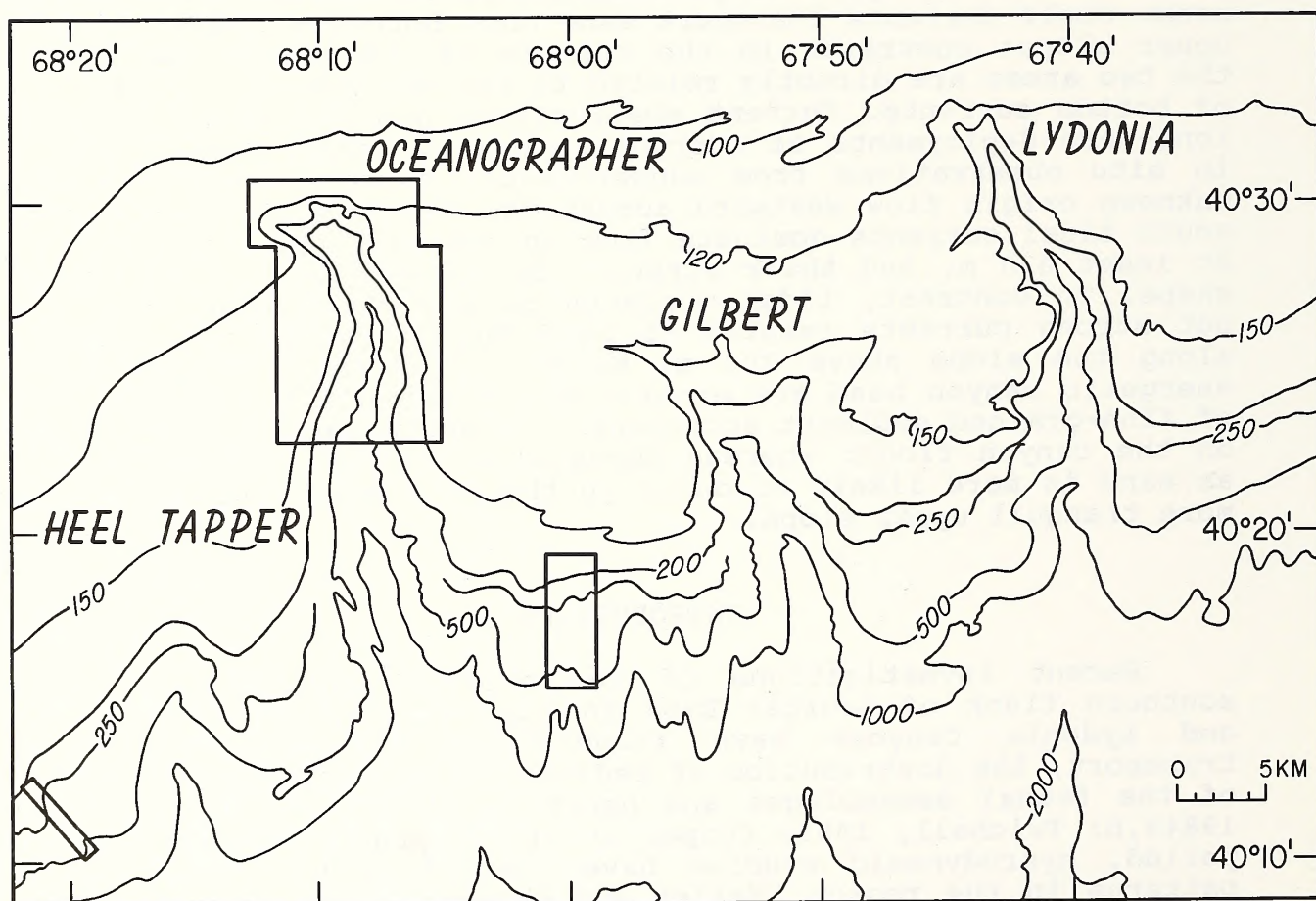


Figure 1. Location of study areas on southern flank of Georges Bank. Most samples from outer shelf-upper slope are from area to east of Oceanographer Canyon (Figure 3B); 5 samples from shelf-slope transition to west of Heel Tapper Canyon are included in textural analyses (Figures 6 and 7).

on the lower canyon walls, the principal source of sediment for both the canyons and the upper slope is relict Pleistocene sand on the shelf.

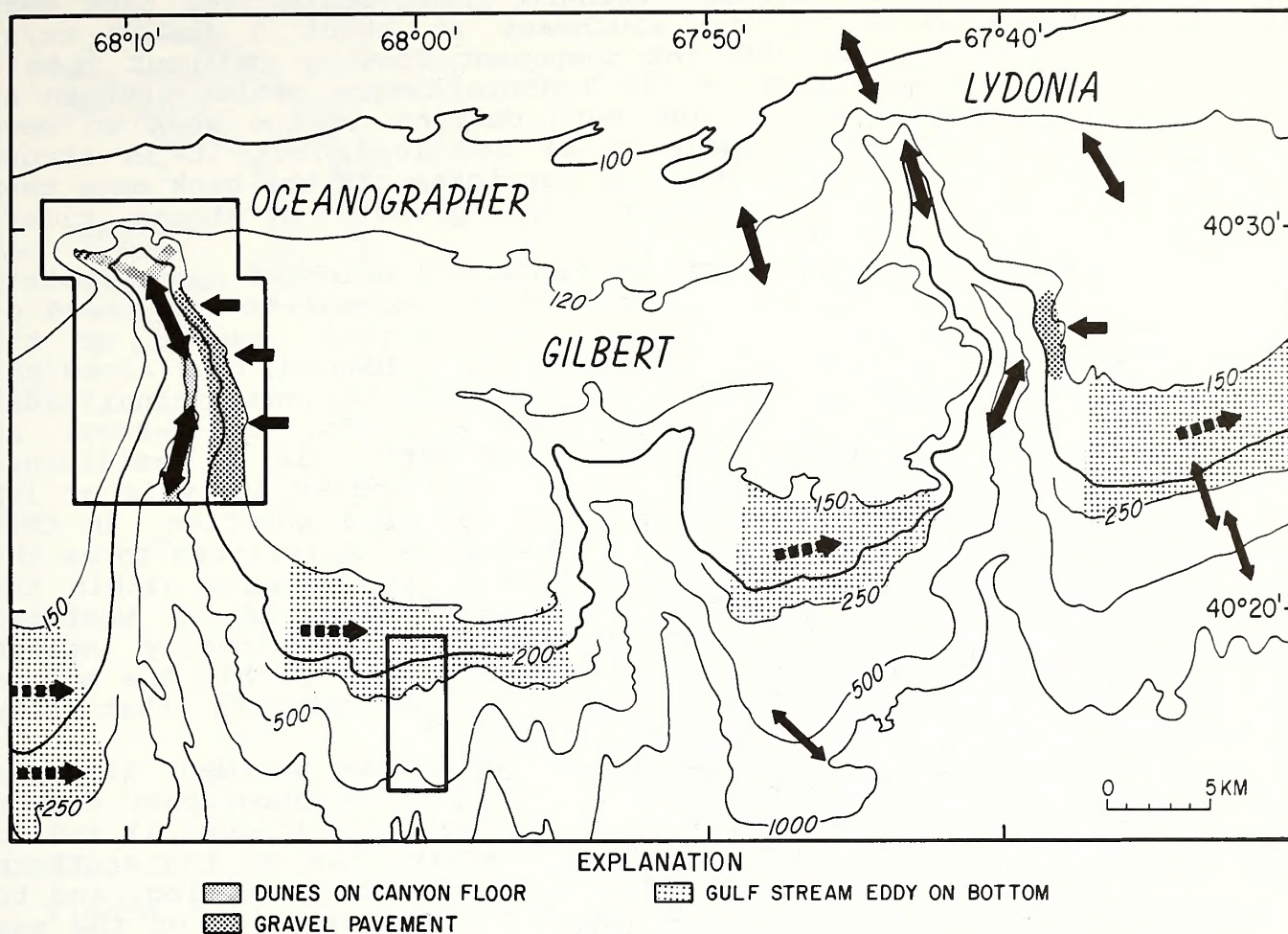


Figure 2. Current patterns and sediment dynamics on the southern flank of Georges Bank. Study areas in Oceanographer Canyon and outer shelf-upper slope to east outlined (Figure 3). Width of arrows represent relative current strength. Two-headed arrows represent major axis of semidiurnal tidal ellipse; arrows in Lydonia Canyon area represent stations of Butman et al. (1983). Tidal currents are strong on shelf and on canyon floors, most energetic in Oceanographer Canyon and diminished on upper slope. West-facing arrows represent strong current on east rim of canyons. East-facing dashed arrows schematically represent strong current associated with Gulf Stream eddies. Mean current is to southwest in this region with a weak off-shelf component near the sea floor (not shown).

Although the region is hydrodynamically complex, recent studies have made it possible to identify several factors that have a major influence on sedimentary processes (Butman et al., 1982, 1983, in press). The seasonal mean circulation flows clockwise around Georges Bank, and its cause has been attributed

to several forcing mechanisms including surface wind-stress, horizontal density gradients such as the shelf water-slope water front, rectification of tidal currents, and regional pressure gradients. On the southern flank of Georges Bank mean flow generally is to the southeast at about 5 to 10 cm/s. However, there is an off-bank component flowing at about 3 to 8 cm/s near the sea floor in the Lydonia Canyon region (Butman et al., 1983, Figure 8-18). The mean current is too weak to move shelf and upper slope sediment as bed load, but it is strong enough to transport silt and clay particles off the bank once they are suspended by more vigorous currents produced by storms, tides, and Gulf Stream eddies.

Strong semidiurnal tidal currents are oriented approximately north-south, parallel to the canyons but normal to the trend of the seaward-facing upper slope. Preliminary results of the Lydonia Canyon experiment show that the strongest flow along the canyon floor reverses direction each day at the semidiurnal tidal period (Butman et al., 1983, Figures 8-25c, d, 8-26c). At present, it is unclear whether this motion is a semidiurnal barotropic tide (M_2) or an internal tide, and an analysis of its internal structure is required to answer this question. In this paper, the reversing flow within the canyons is referred to as the semidiurnal tide. In addition to the tidal currents within the canyons, a strong current of uncertain origin flows westward across the canyon rims. Gulf Stream eddies occasionally impinge on the southern flank of the bank; circulation within the eddies is clockwise and produces strong bottom currents that flow eastward along the upper slope.

The purpose of this paper is to describe sediment textures that lie within the same depth interval in Oceanographer Canyon and on the adjacent outer shelf and upper slope (Figure 1) and to relate sediment dynamics in the two areas, and on the southern flank of Georges Bank in general, to sea floor morphology and to prevailing current systems. Observations and sampling of the sea floor were carried out by submersible and supplemented by grab sampling and bathymetric surveys from a surface ship (Figure 3). In a study of this nature, the use of a submersible is necessary for sampling areas such as steep walls, narrow canyon and gully floors, and localized sedimentary environments that are inaccessible to grab samplers or difficult to locate from a surface ship.

SEDIMENT TRANSPORT AND CURRENTS

Oceanographer Canyon

Oceanographer Canyon, the largest of the Georges Bank canyons, incises the shelf some 22 km and exhibits many different bottom types. The surficial geology of the northern part of this canyon has been treated elsewhere and only a brief description is presented here (Valentine et al., 1980, 1984a, b). Coarse to fine rippled shelf sand is present around the canyon to about 150 m where it gives way to gravel and gravelly sand on the rim (Figure 4). The upper walls are generally covered by a thin veneer of rippled silty sand; the silt is incorporated into the sand from

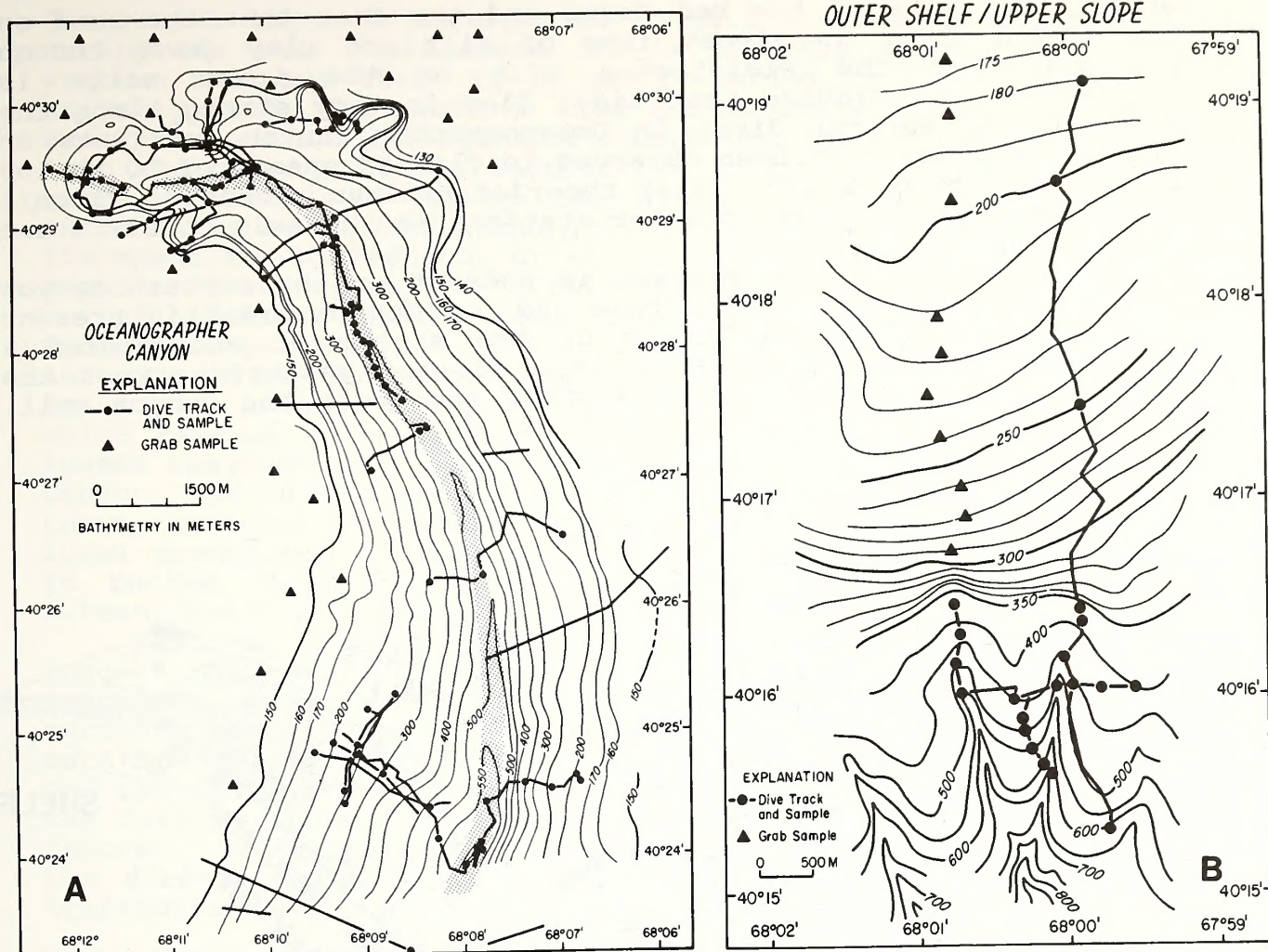


Figure 3. A) Oceanographer Canyon, northern part, showing dive tracks and locations of sediment samples; dot pattern represents canyon floor where strong tidal currents flow and where rippled sand and dunes are present. B) Outer shelf-upper slope east of Oceanographer Canyon showing dive tracks and locations of sediment samples. Textures of samples from canyon floor and from outer shelf-upper slope presented in Figures 6 and 7.

below by burrowing infaunal organisms, chiefly annelid worms. The lower canyon walls exhibit broad exposures of semiconsolidated silt of Pleistocene age that is often burrowed by crustaceans. The canyon floor is covered by dunes of coarse to medium rippled sand.

Bed forms and sediment textures indicate that bottom currents are very energetic within the canyon and on the shelf around it (Figure 2). The canyon is oriented approximately north-south, parallel to the strong semidiurnal tide which is the strongest current flowing along the axis here and in adjacent Lydonia Canyon (Butman et al., 1983). Ripples in sand on the canyon walls are generally aligned normal to the tidal flow as are large asymmetrical dunes on the canyon floor that range up to 3 m in

height. The size of the bed forms and the fact that the sand on the canyon floor is almost free of silt and clay (even though bioerosion of the Pleistocene silt on the lower walls is extensive) are evidence that tidal flow is very strong along the axis. During several dives in Oceanographer Canyon, currents on the canyon floor have been observed to flow at speeds of 50 to 100 cm/s, and Butman et al. (1983) recorded maximum speeds of 73 cm/s and 96 cm/s at two current meter stations in the axis at 227 m and 560 m, respectively.

Another major flow pattern is present on the eastern canyon rim where a large area of cobble and boulder pavement is present between 150 and 275 m. Dives up the east wall encountered a strong current of at least 50 cm/s flowing westward across the gravel. This current transports shelf sand onto the canyon wall.

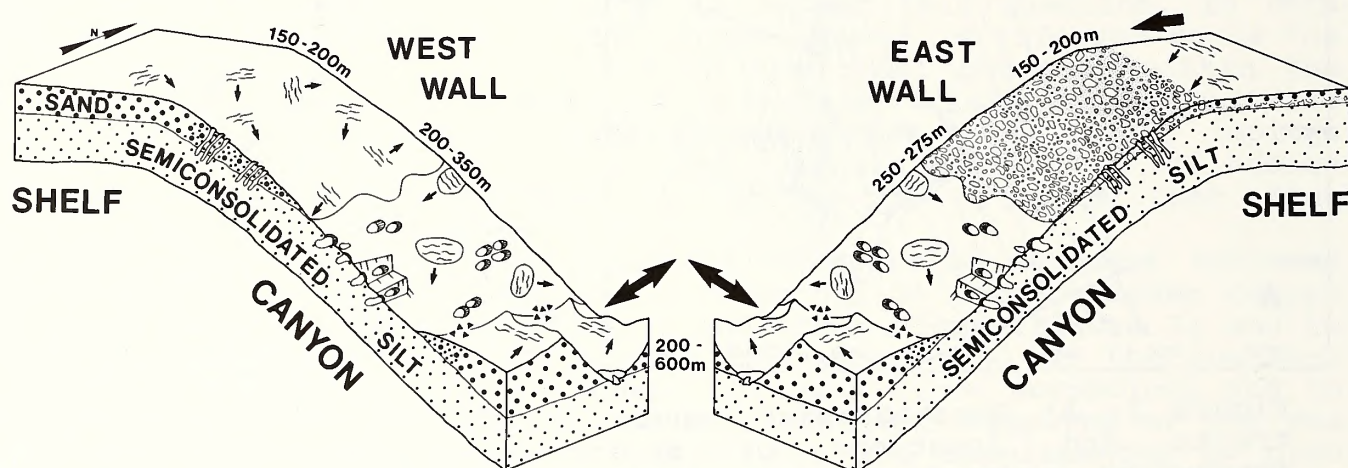


Figure 4. Oceanographer Canyon; schematic oblique view of east (right) and west (left) walls looking north, upcanyon; no scale. West wall: rippled shelf sand and gravelly sand transported down wall (small arrows) by tidal currents aided by gravity; annelid burrows into underlying silt (elongate symbols); sand probably overlies gravel deposits similar to those exposed on east wall; Pleistocene silt exposed on lower wall and burrowed by crustaceans (oval symbols); solid triangles at base of wall represent eroded silt fragments; large, asymmetrical, rippled sand dunes migrate up- and downcanyon floor in response to strong tidal flow (two-headed arrows) and fine sediment winnowed. East wall: strong westward current (one-headed arrow) transports shelf sand onto wall and exposes ice-rafted glacial deposits.

The gravel layer is interpreted to be ice-rafted debris deposited during the late Pleistocene. It is probably also present on the western rim, but there it is partly buried by shelf sand to form gravelly sand. The westward flow across the eastern rim is strong enough to winnow and transport sand through the gravel downslope into the canyon, but is ineffective in transporting sand up-slope onto the shelf to expose the gravel on the western rim. The current may be discontinuous, or in its passage across the canyon its speed may be reduced, or at full strength it simply may not be capable of moving sand back onto the shelf.

A similar current has been observed on the east rim of Lydonia Canyon (Butman et al., 1983). The current is oscillatory, and major flow directions are east and west. However, the current is unusual because eastward flow is much weaker than westward flow which reaches hour-averaged speeds of 50 cm/s or more, similar to speeds observed from submersibles on the east rim of Oceanographer Canyon. The origin and extent of this distinctive current is not known, although the sparse data available suggest that it may be a local phenomenon in part related to tidal effects and to changes in bottom morphology and water depth at the canyon edge (B. Butman, personal commun., 1984).

Textural analyses, bedform orientation, and current patterns suggest that storm currents and strong semidiurnal tidal currents transport sand off the shelf onto the canyon walls. Tidal currents move it up- and downcanyon along the wall and eventually onto the canyon floor; subsequently, the sand is transported up- and downcanyon along the floor, formed into ripples and dunes, and the fine sediment derived from bioerosion of the canyon walls is removed. Superimposed on this north-south transport pattern is the strong current that flows westward across the east rim and transports shelf sand onto the canyon wall.

Outer Shelf and Upper Slope

The principal outer shelf-upper slope area under study is located about 9 km east of the mouth of Oceanographer Canyon (Figures 1, 3B). In addition, a suite of 5 samples from a similar setting to the west of Oceanographer Canyon is included in the study (Figure 1). The sea floor from the outer shelf down to about 650 m on the upper slope is a relatively homogeneous sheet of sand that becomes increasingly silty with depth (Figures 5 and 6). Sand present from 175 m to about 300 m contains 5% or less silt and clay and is typical of shelf sand around the canyons, but silt and clay increase in weight to about 36% at 640 m on the gullied upper slope. Scattered patches of gravel are present in the shelf-slope transitional area, suggesting that ice-rafted gravel deposits are present but have been buried to a large extent by the layer of sand. The gullies that "head" at about 350 m have walls that are inclined at 35° to 40°. However, the underlying Pleistocene silt that is so extensively exposed in Oceanographer Canyon is rarely observed. Ripples are rare at outer shelf depths greater than about 190 m, and the gully floors are covered by a smooth layer of silty sand. Gravity slides initiated by contact of the submersible with the gully walls suggest that the silty sand is at or near its angle of repose.

These observations indicate that the outer shelf-upper slope region experiences weaker currents than does the nearby canyon within the same depth interval (Figure 5). The upper slope is oriented normal to the semidiurnal tide, and Butman et al. (1983, Figures 8-24a, 8-24b) have shown that semidiurnal tidal currents become weaker with depth at two stations located at 250 m and 571 m on the slope east of Lydonia Canyon, about 35 km east of the present study area (Figure 2). The most vigorous currents on the upper slope are associated with Gulf Stream eddies and flow eastward at hour-averaged speeds up to 45 cm/s at about 250 m (Butman et al., 1983). It is apparent that storm currents transport shelf sand onto the upper slope where it becomes mixed with an increasing amount of silt and clay through the activities

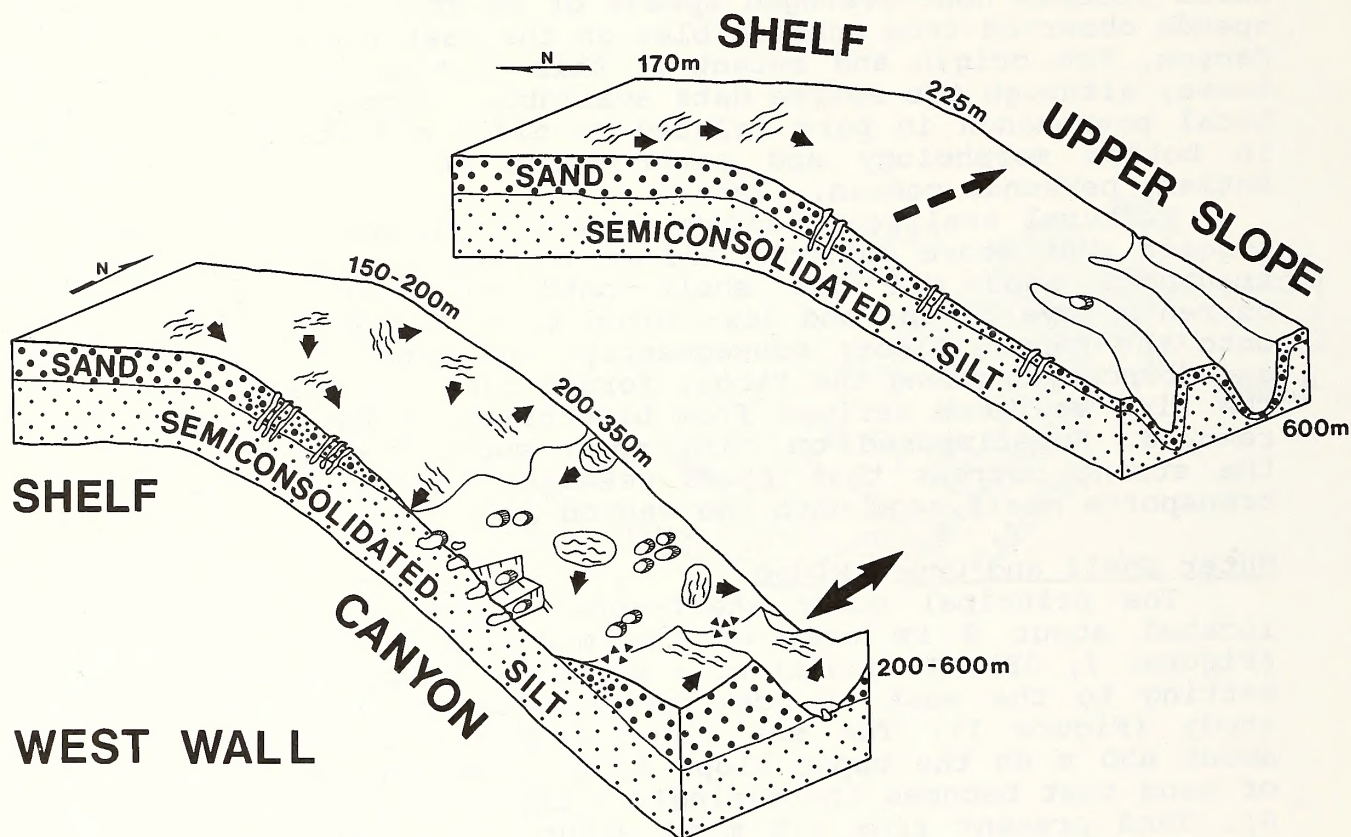


Figure 5. Oceanographer Canyon and adjacent outer shelf-upper slopes; schematic oblique view of canyon west wall looking north, upcanyon, and of outer shelf-upper slope looking east, along slope; no scale. West wall: (as in Figure 4). Outer shelf-upper slope: rippled shelf sand transported to outer shelf (solid arrows) chiefly by storm currents; annelid burrows into underlying silt (elongate symbols); along-slope transport to east above 250-300 m by Gulf Stream eddy currents (dashed arrow); bedforms rare or absent on upper slope, and not observed on gully floors; crustacean burrows in Pleistocene silt rare (oval symbol); silty sand on steep gully walls at angle of repose.

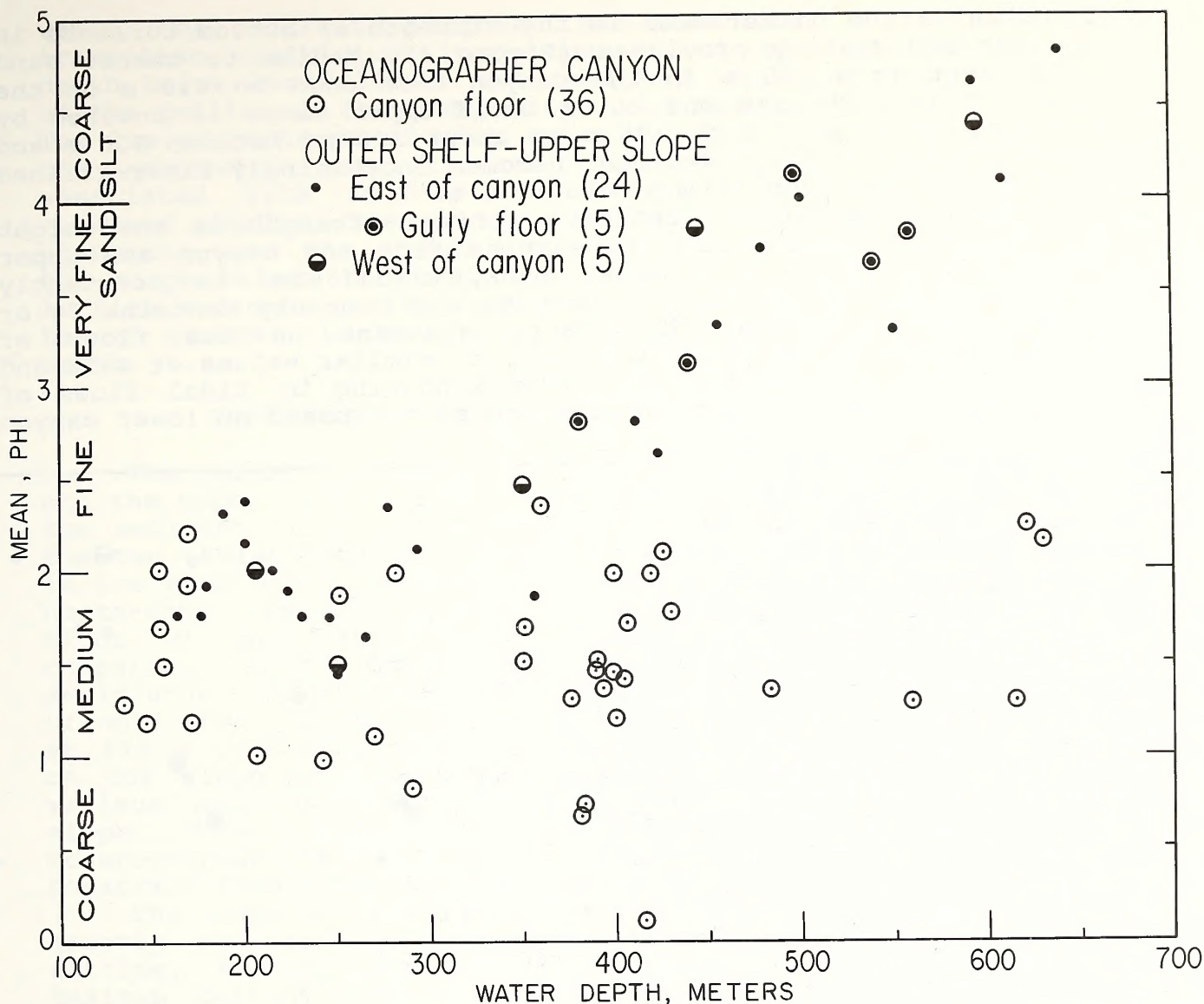


Figure 6. Mean grain size (phi) versus depth for sediment samples from the floor of Oceanographer Canyon and from the adjacent outer shelf-upper slope. Note that upper slope samples are finer grained than canyon samples in water depths greater than about 300 m. Sediment from floor of slope gullies is no coarser than other slope sediment at equivalent depths.

of small organisms that burrow into the underlying silt and through deposition from suspension. Bioerosion of Pleistocene silt by crustaceans is minor because the relatively weak currents on the slope cannot remove the veneer of sand from even the steep gully walls.

Sediment Texture and Current Strength

Keeping in mind that the shelf is the source of sand for both the canyon and the slope, a comparison of the mean grain size of sediment collected from the floor of Oceanographer Canyon and from the same depth interval on the outer shelf-upper slope region

illustrates the differences in the strength of bottom currents in the two sedimentary provinces (Figure 6). Medium to coarse sand is present from 135 m in the canyon head down to 630 m on the canyon floor, whereas the outer shelf-upper slope is covered by fine to medium sand from 175 m to about 300 m. Between 300 m and 640 m, the upper slope sediment becomes increasingly finer-grained with coarse silt dominating below 600 m.

Another measure of relative current strength is the weight percent of silt and clay in samples from the canyon and upper slope (Figure 7). On Georges Bank, shelf sand is constantly reworked by tidal and storm currents and commonly contains 5% or less silt and clay. The coarse sediment on the floor of Oceanographer Canyon typically exhibits similar values of silt and clay content that result from the winnowing by tidal flows of fine-grained sediment eroded from the silt exposed on lower canyon

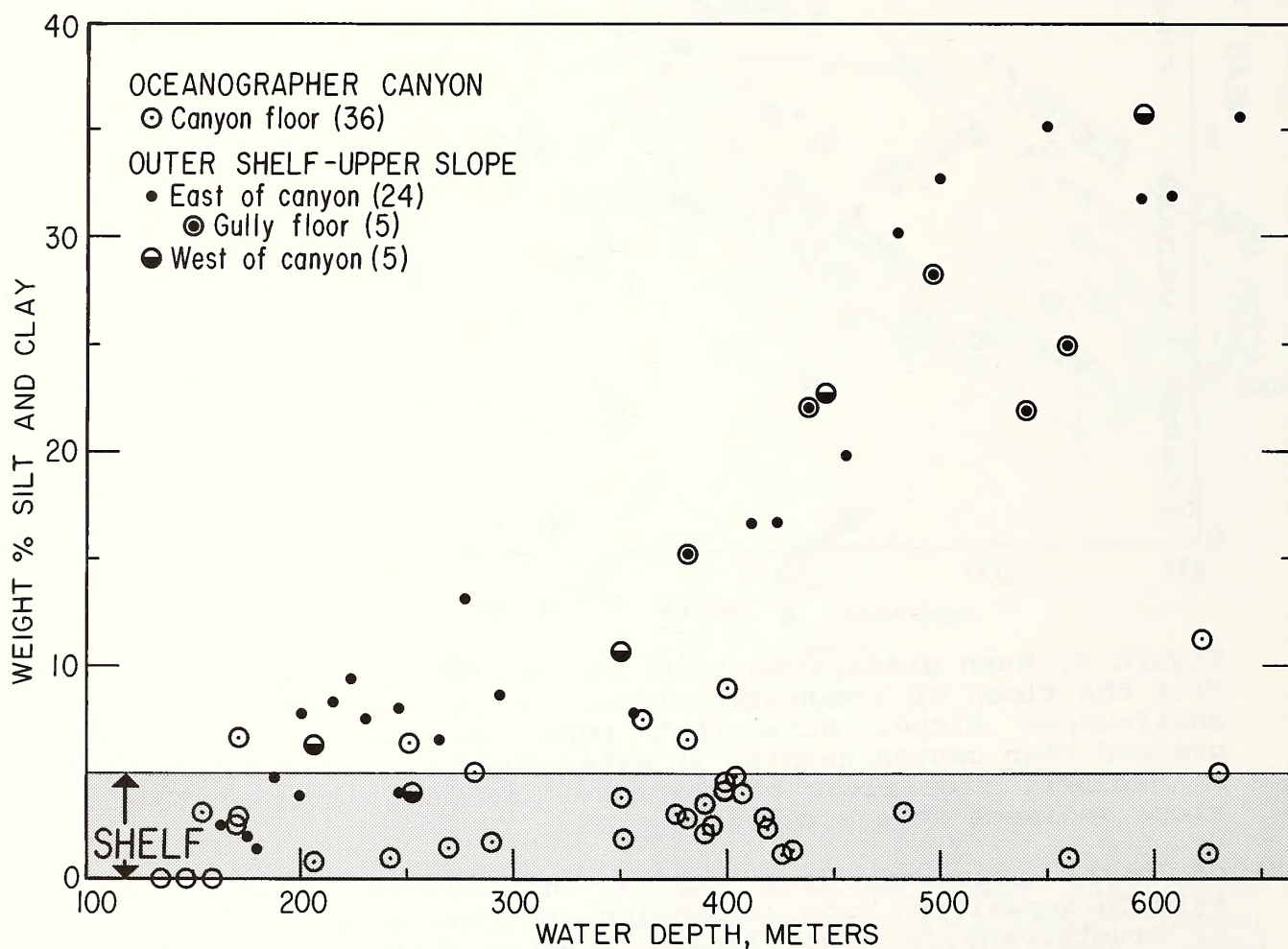


Figure 7. Silt and clay weight percent versus depth for sediment samples from the floor of Oceanographer Canyon and from the adjacent outer shelf-upper slope. Silt and clay content of Georges Bank shelf samples at depths to 200 m typically 5% or less. Note increase of silt and clay in upper slope sediment below 300 m. Sediment from floor of slope gullies also contains large percentages of silt and clay.

walls. By contrast, samples from the outer shelf-upper slope transition contain an increasing amount of silt and clay with depth below about 300 m. Even sediment collected from the floors of the gullies on the upper slope does not depart from this trend. The low percentages of silt and clay above 300 m may result from the winnowing activity of the relatively strong currents associated with Gulf Stream eddies (Figure 2). The eddies observed during the Lydonia Canyon experiment were shallow phenomena, and the strong currents at their base did not affect the slope below about 250 m (Butman et al., 1983). The increase in fine sediment on the upper slope below 300 m can be attributed to a general weakening of tidal and storm currents with depth.

INFLUENCE OF CANYON SIZE AND SHAPE ON CURRENTS

The sedimentary deposits on the floor of Oceanographer Canyon and the upper slope are very different texturally, yet the bulk of the sediment found in both areas is derived from shelf sand, and the two sedimentary provinces are located adjacent to one another in the same depth interval (150-650 m). Both areas experience the north-south semidiurnal tide, and maximum tidal currents along the floor of the canyon reach speeds of 50 to 100 cm/s. In comparison, on the upper slope near Lydonia Canyon all 5 principal semidiurnal and diurnal tides combine to produce maximum currents of only about 12 cm/s at 245 m (5 meters above bottom) and 5 cm/s at 471 m (100 mab) (Moody et al., 1984). The strongest currents on the slope are associated with Gulf Stream eddies and reach maximum hour-averaged speeds of about 45 cm/s directed along slope. Tidal forces are aligned parallel to the axis of Oceanographer Canyon, suggesting that its size and shape may constrain flow direction and enhance flow speed.

The canyons on the southwestern flank of Georges Bank vary greatly in size. Although they share the same physiographic setting, the differences in bedforms, sediment texture, and maximum current speeds observed so far indicate that current energy levels also differ in these canyons. Sand dunes of medium to coarse sand up to 3 m in height are present on the floor of Oceanographer Canyon, the largest of 12 canyons that incise the shelf in this region. Dunes also have been reported from the floor of Hydrographer Canyon, the second largest canyon (Southard and Stanley, 1976, p. 368; Keller and Shepard, 1978, p. 30). The floor of Lydonia Canyon, the fourth largest canyon, is covered by fine to medium rippled sand (Twichell, 1983; Butman, et al., 1983) and for the most part it is finer grained than that found in Oceanographer Canyon. However, a dive along the axis of Lydonia Canyon traversed an area of rippled sand and low dunes at a depth of about 600 m (B. Butman, personal commun., 1984). Sediment collected from this area is the coarsest found on the canyon floor and contains only about 10% silt and clay (Butman et al., 1983, Figures 8-11a, b, c). The floors of other canyons have not been surveyed or sampled thoroughly. Bottom photographs obtained on dives by scientists of the U.S. Geological Survey and the National Marine Fisheries Service reveal the presence of fine-grained sediment and ripple marks on the floor of Veatch Canyon,

the fifth largest canyon. Atlantis Canyon, the second smallest of the 12 canyons considered here, exhibits a locally rippled floor of fine-grained sediment.

If sediment dynamics differ in canyons that share a common sediment source and a similar hydrodynamic setting, there should be a correlation between canyon size or shape and the speed of the dominant current, the semidiurnal tidal flow. It is not yet known whether the strong bottom currents in the canyon are caused by the semidiurnal barotropic tide (M_2) or by a semidiurnal internal tide that is set up by the interaction of the M_2 tide with the canyon walls and floor. Hotchkiss and Wunsch (1982) studied internal tides in Hudson Canyon and the effect of canyon shape on current strength. They concluded that the strength of the internal tide depends in a complex way on the strength of the surface tide, canyon length, cross-sectional area, and the slope of canyon walls and floor.

The present study does not have the hydrodynamic data to determine quantitatively the effect of canyon shape on current strength. However, it is possible to make a qualitative determination by comparing the sedimentary environments observed in the Georges Bank canyons with canyon morphology. The volume, axial length, mouth height and mouth width were calculated from the 12 canyons that incise Georges Bank shelf from Powell Canyon in the east to Alvin Canyon in the west (Figure 8). These measurements were arbitrarily limited to the region between the canyon head and the shelf edge at the 200 m isobath, because the most active currents are found there [based on sediment texture and bedform analysis and on current speeds measured by Butman et al. (1983)].

The largest canyon considered here (Oceanographer) is more than 50 times larger than the smallest (Shallop), and there is a strong positive correlation between axis length and canyon volume ($r = 0.88$) and between mouth height and canyon volume ($r = 0.92$). However, the width of the canyon mouths does not vary in a systematic way with volume ($r = 0.10$). Oceanographer and Hydrographer Canyon are larger, longer, and deeper than the others, and based on the evidence presented above, they are the most energetic of all the canyons. It is difficult to ascertain whether the "energy level" of a canyon depends on its volume or is related to a combination of volume, axial length, and mouth height. Gilbert and Lydonia are the third and fourth largest canyons, respectively. Gilbert has the higher mouth of the two, but Lydonia is longer. Further study of Gilbert and some other canyons is needed to resolve this issue. At present, canyon volume is inferred to be an important factor, and based on volume alone, the 12 canyons are categorized preliminarily into groups representing high, moderate, and low energy levels.

Oceanographer and Lydonia Canyons are the best known canyons with regard to sediment textures, bedforms, and bottom currents. Oceanographer is almost five times larger than Lydonia, and this difference in volume apparently affects the strength of currents on the canyon floors. Bottom currents in Oceanographer and Lydonia reach maximum speeds of about 100 cm/s and 50 to 60 cm/s, respectively, and produce quite different sedimentary environments in canyons that are located only 40 km apart. Heel Tapper Canyon

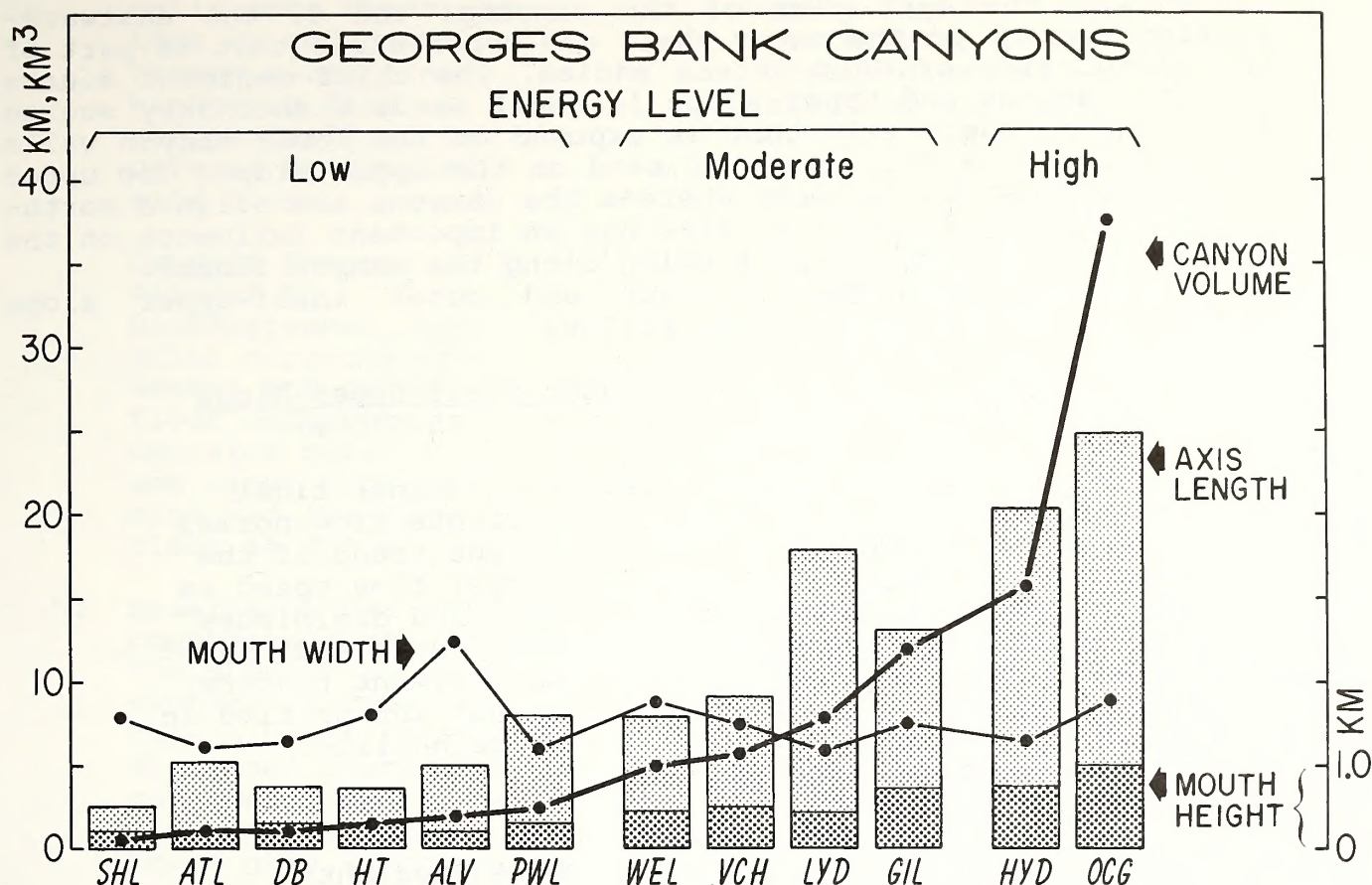


Figure 8. Dimensions and energy levels of 12 Georges Bank canyons. Dimension measured from bathymetry by Carpenter et al. (1982). Canyons arranged left to right in order of increasing volume. Canyon names: SHL, Shallop; ATL, Atlantis; DB, Dogbody; HT, Heel Tapper; ALV, Alvin; PWL, Powell; WEL, Welker; VCH, Veatch; LYD, Lydonia; GIL, Gilbert; HYD, Hydrographer; OCG, Oceanographer.

is a small canyon that lies adjacent to Oceanographer Canyon and shares the same environmental setting (Figures 1 and 8). This canyon has not been visited with a submersible or sampled, but based on size alone, one would infer from the foregoing discussion that its energy level is low, perhaps more similar to that of the upper slope than to that of its large energetic neighbor.

SUMMARY

The major geologic and hydrodynamic factors that shape the sedimentary environments present in the Georges Bank canyons and on the intervening upper slope include the current regime, the sediment source, and the physiographic setting of the southern flank of the bank (Fig. 2). The bottom-current systems most important in eroding and transporting sediment in this region are: a. storm currents on the shelf; b. north-south semidiurnal tidal currents on the shelf and in the canyons; c. the westward-flowing

current on the east rims of the canyons; and d. the eastward-flowing current on the outer shelf and upper slope that is part of the circulation of Gulf Stream eddies. The chief sediment source for the canyons and upper slope is shelf sand; a secondary source is the Pleistocene silt that is exposed on the lower canyon walls and covered by a thin layer of sand on the upper slope. The upper slope is oriented east-west whereas the canyons are aligned north-south, and canyon shape and size has an important influence on the strength of tidal currents flowing along the canyon floors.

A comparison between canyon and outer shelf-upper slope sedimentary environments areas follows:

<u>Canyon</u> (135-630 m)	<u>Outer Shelf-Upper Slope</u> (175-640 m)
1. Semidiurnal tidal currents flow parallel to canyon axis; canyon size and shape intensify tidal flow speeds, and the largest canyons are most energetic; speeds reach 100 cm/s in Oceanographer Canyon.	1. Semidiurnal tidal currents flow normal to the trend of the slope; flow speed is weak and diminishes with depth and, based on sediment texture, is not intensified in slope gullies.
2. Westward flow of 50 cm/s of unknown origin exposes gravel on east rims of Oceanographer and Lydonia Canyons and transports shelf sand onto east wall.	2. No equivalent westward flow.
3. Gulf Stream eddy circulation is not present below about 250 m and is not a major factor influencing bottom flow in canyon.	3. Eastward currents with speeds up to 45 cm/s are associated with warm Gulf Stream eddies and affect outer shelf and upper slope sediment to about 250 m.
4. <u>Oceanographer Canyon</u> : shelf sand is transported onto canyon walls by storms and tidal currents and onto east wall by westward along-shelf current; tidal currents move sand along and down	4. Shelf sand is transported onto gullied upper slope principally by storm currents; along-slope transport to east is by Gulf Stream eddy currents; ripples are rare below about 190 m; no bedforms on

walls onto floor and then up and down canyon along floor winnowing fine sediment; floor is covered by rippled sand dunes.

Lydonia Canyon:

similar to Oceanographer, but axial currents are weaker and canyon floor sediment contains more silt and clay; rippled sand and low dunes on floor at 600 m.

5. Bioerosion by crustaceans of Pleistocene silt exposed on lower canyon walls is major erosional process in canyons; fine sediment is most thoroughly winnowed from canyon sand in larger canyons.

6. Large canyons: bioerosion of lower walls; accumulation of mobile sand on floor and winnowing of fine sediment.

Small canyons: walls draped with sand from shelf, sand on floor is less mobile and contains more silt and clay; similar in some respects to sedimentary environment of upper slope.

gully floors. Sand contains an increasing amount of silt and clay with depth. Sediment lies at angle of repose on steep gully walls and moves onto gully floor by creep and gravity slides.

5. Pleistocene silt rarely exposed and few crustacean burrows; widespread sand sheet makes burrow openings difficult to maintain.

6. Principally an environment of deposition; old gullies incised into Pleistocene silt are draped with sand from shelf; fine-grained sediment increases with depth.

These observations suggest that within the outer shelf-upper slope transition region the large canyons are chiefly sites of erosion and transport of fine-grained sediment and of accumulation of sand on the canyon floor, whereas deposition of both fine sediment and sand is the most important process in the less energetic, small canyons and on the seaward-facing upper slope.

ACKNOWLEDGEMENTS

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CHAPTER V

OCEAN SERVICES

A POTENTIAL UNTETHERED ROV FOR OCEAN SCIENCE

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ABSTRACT

Untethered (autonomous) vehicles are not typically designed to replace conventional tethered (remotely-operated vehicles), however, freedom from the tether offers distinct advantages which will allow free-swimming vehicles to serve as alternatives to ROV's and manned submersibles. Advantages include, minimal handling system requirements, increased horizontal and vertical range of operations, and reduced energy expenditure (no cable drag). Recent technology which has facilitated tether removal includes the development of microprocessors, robotics, high energy-density batteries, optical fibers, acoustic communication (including telemetry) links, and strong lightweight materials. Five autonomous vehicles in use and/or under development are described: SPURV II, Epaulard, AUSS, EAVE-East, and ARCS. Finally, a preliminary autonomous vehicle system concept, formulated by the University of New Hampshire's Marine Systems Engineering Laboratory (MSEL), is presented. This system will be designed to meet the needs of ocean scientists working from small support vessels, at water depths of less than 500 m.

INTRODUCTION

Intelligent free swimming vehicles are the subject of research and development efforts in at least 11 laboratories throughout the United States and Europe. The research efforts are focused on developing technology and prototype vehicles to perform underwater inspection and light work tasks.

Remotely operating vehicles (ROV), controlled from the end of power and communication tethers, have proved to be successful in many offshore applications. The vehicle carries sensors, imaging sensors in particular, to convey information to a remote operator, while manipulators serve as an extension of his hands. Some on board computation is usually provided in the form of controllers. An enviable record of success has been achieved with tethered ROVs, and indeed, one may ask why attempts should be made to remove the tether. Obviously an untethered vehicle has no access to external power, and must carry the energy for the entire mission on board. The mission duration is thus restricted and only limited power is available for physical work. The communication link, deprived of direct connection, becomes limited indeed. Without access to an operator, the vehicle must itself make crucial decisions to ensure its safety, and the success of its mission.

It is apparent that the conventional ROV will continue to serve with distinction in its prime areas of application. However, as the range of operation becomes longer, and water depth increases, the drag exerted by the tether becomes a major

limiting factor to operational effectiveness. The thrusters, and therefore the vehicle, must become larger, the cable thicker, and the energy that will go into overcoming cable drag will become a limiting factor. Surface ship handling facilities must become massive and the situation becomes self-limiting.

An untethered vehicle needs the same power at any depth. Entanglement of the tether, a common concern in ROVs, is eliminated. Surface ship handling systems become almost trivial. Moreover, many classes of untethered missions have been recognized which are essentially inspection and information gathering functions where manipulation and heavy work are not required. Many of the requirements of ocean science also do not demand tethered systems. In addition, they offer relief from the expense of the manned submersibles currently in use. In most of these missions, the constraints of on board energy sources, therefore, are not limiting factors, and all represent desirable applications for an intelligent untethered robotic submersible.

Any considerations of removing the tether would have been quite impossible before the advent of the microcomputer. Within the past few years, however, new technologies have appeared which offer much promise for greatly reducing the need for on-line operator control. This technology -- robotics -- someday will allow machines to be programmed in advance to perform specified tasks, to reason, to communicate and to handle many complex problems with on board intelligence.

At the root of this technology are microprocessors, chip-sized computers, which can be arranged in large scale integrated circuits to perform the various necessary computations and to make key decisions. Together with other new developments, such as high energy-density batteries, optical fibers, acoustic communication links and strong lightweight materials, robotic submersible development can begin in earnest. The successful development of such vehicles (variously referred to as unmanned, untethered vehicles, unmanned free swimmers, supervisory controlled vehicles, or even autonomous vehicles) will provide alternative solutions to the increasingly perplexing problems regarding effective underwater inspection and work at minimum cost, improved reliability, greater range and unlimited depth.

Following are capsule descriptions of some ongoing autonomous vehicle developments:

SPURV II

Applied Physics Laboratory (APL), University of Washington, Seattle, Washington, has pioneered in the field of autonomous vehicle systems since 1959 with the UARS (Undersea Arctic Research Submersible) development in the 1960s and subsequent SPURV (self-propelled underwater research vehicle) of the early 1970s. The latest, called SPURV II, is an instrumentation platform for oceanographic research. It became operational in 1975 and was extensively modified in 1979.

Specifications:

Length - 4.57 m (15 ft)
 Weight - 454 kg (1300 lbs)
 Diameter - 50.89 cm (1.67 ft)
 Maximum depth - 1500 m
 Speed - to 3.0 m/s
 Endurance - to 7 hrs
 Propulsion - single 1 hp motor
 Power - 23.25 kWh silver zinc battery
 Payload - temperature, pressure, conductivity, sensors and
 fluorometer

Navigation and control is provided by a shipboard operator aided by an acoustic link. On-board operational sensors include heading, depth and speed.

Epaulard

CNEXO (Centre National pour l'exploitation des Oceans), La Seyne sur Mer, France, has led the development of an operational vehicle, the Epaulard, with a superb success record. The mission is to conduct deep water bottom photography, and topographic profiling studies. From its launch in 1979 to mid-1981, Epaulard had 72 dives, 40 of them to depths of between 1000 and 5300 meters. The vehicle descends with a dive weight which is discarded on the bottom, maintains altitude with a drag chain, and discards an ascent weight to reach the surface. Its course is controlled by an acoustic link from the surface.

Epaulard specifications include:

Depth - 6,000 m
 Speed - up to 2.5 knots
 Duration - 10 hours
 Range - 12 nmi
 Hull material - titanium
 Length - 4 m (13.12 ft)
 Beam - 1.1 m (3.6 ft)
 Weight in air - 3 tons (2.730 kg)
 Propulsion - 1 thruster with rudder steering
 Power source - 18 kWh lead acid batteries
 Command control - internal heading follower, acoustic command and
 measurement
 Computer - two 8080 and three UP141 microprocessors
 Instrumentation - 35 mm, 5000 exposure still camera, temperature,
 altitude, depth and heading.
 Launch/Retrieval - A-frame or crane.

AUSS

Naval Ocean Systems Center (NOSV) San Diego, California, has been developing the AUSS (advanced unmanned search system). It has four objectives relative to autonomous vehicle development. They include:

- . Analysis to determine optimal means of conducting deep ocean search.
- . A testbed for verification of deep ocean search technologies.
- . Component and subsystem test and evaluation.
- . Development of a data acquisition system which explores the optimal data gathering instrumentation.

The specifications of the AUSS include:

Hull - graphite cylinder with titanium endbells.
 Length - 14 ft (4.27 m)
 Diameter - 30 in (.76 m)
 Displacement - 2000 lbs (969 kg)
 Operating depth - to 20,000 ft.
 Power - silver zinc batteries
 Navigation - dead reckoning with doppler sonar transponder positioning
 Propulsion - two stern thrusters for forward motion and yaw (turning), two vertical thrusters for heave
 Communication - vertical acoustic link, 4800 bits/sec. up link, 1200 bits/sec down link, bit error rate 1 in 100,000

EAVE-East

The EAVE-East (Experimental Autonomous Vehicle) is a testbed for technology development. It has completed tests to demonstrate the ability to autonomously follow an underwater pipeline and maneuver inside an underwater structure using an on board, high resolution (± 10 cm), acoustic navigation system. The current emphasis is to develop a knowledge-based guidance and control system.

EAVE-East Specifications include:

Size - 4' x 4' x 4'
 Weight - 750 lbs
 Maximum depth - 1000 ft.
 Speed - 2 knots
 Endurance - 8 hrs
 Propulsion - 6 - 0.25 hp thrusters
 Power source - 2kWh (24, 16Vdc)
 Payload - 50 lbs
 Computer system - 2 - 6100, 2 - 68000, 1 - 9511
 Navigation - short baseline/long baseline
 Data storage - 256Kbyte magnetic bubble memory

ARCS

Bedford Institute of Oceanography (BIO), Dartmouth, Nova Scotia, Canada, has contracted with International Submarine Engineers of Port Moody, British Columbia, to construct the ARCS vehicle (autonomous remotely controlled submersible). The diving mission of the ARCS is to conduct bathymetric surveys in ice-covered waters.

System specifications include:

Endurance - 100 nmi

Design depth - 1200 ft (366 m)

Speed - 5 knots for 20 hours

Maximum distance from a control station - 10 mi (16 km)

Torpedo shaped - length 15 ft (4.4 m)
diameter 21 in (53.3 cm)

Displacement -2200 lbs (1000 kg)

Sensors - bathymetric and ultimately seismic and sidescan sonar.

Sperry C11 gyroscope, depth, Doppler sonar.

Navigation - acoustic beaconry, accuracy of 5 m Oceano long baseline system

Thruster - 1/2 hp electric motor

Battery - 110 Ah, 120 V nickel cadmium

Controllable - out to 5 miles in 100 feet of water

Status - prototype sea trials planned in late 1983.

These programs are by no means the only efforts directed at the utilization of unmanned untethered submersible vehicles. The Marine Systems Engineering Laboratory at the University of New Hampshire has held a series of symposia directed at this technology. Most of the other programs are described in the proceedings from these symposia (the third was held June 6-9, 1983).

The Marine Systems Engineering Laboratory (MSEL) has been considering an unmanned untethered system which would be directed at the needs of the ocean scientist using a small support ship working in relatively shallow water (500 meters) similar to many of the programs in the Gulf of Maine. Much of the research and development program at MSEL over the past eight years has been directed toward the robotic sciences and technologies as applied to underwater and oceanic systems. The EAVE-East vehicle system described above has been used as a testbed for the development of technologies pacing the utilization of unmanned untethered submersible systems. Current efforts have addressed the problems of placing interactive intelligence on the vehicle. As this level of intelligence increases, the potential of unmanned untethered vehicle systems will increase dramatically.

Building on the experience gained from the development of the EAVE-East vehicle, a preliminary vehicle system concept for coastal and continental shelf missions (0-500 m) has been bounded. This system is meant to compliment the capabilities provided to ocean science by systems such as manned submersibles and remotely operated, tethered vehicles.

The proposed untethered vehicle system would address the following constraints:

Suitability for use on small support ships

The system would be usable from a support ship no larger than 40-50 feet. It would require only a simple A-frame capable of placing 1000 lbs into the water. The control console for the system must be small enough to be easily placed on the support ship.

Easily transportable to a user location

In order to minimize the logistics problems which limit the use of ROVs and, more substantially, manned submersibles, the proposed system must be easily transported. The entire system, with its support equipment and a reasonable inventory of spare parts must fit into a van or similar container.

Reprogrammed in high level languages

It is important that much of the system software be transparent to a user. Modification of the system to specifically meet the user's specific needs is, however, very important. This can be accomplished by incorporating into the system software, high level language commands which drive specific vehicle system functions. Experience with the EAVE-East vehicle has proven the effectiveness of this concept (i.e. "hover", "go to point x,y,z", "take 10 pictures", etc.).

Simple Sensors/Tools

There are many tasks which can be accomplished with relatively simple/standard sensors or tools. It is felt that a camera system (35 mm, CCD) and a 1 or 2 function manipulator will offer substantial capabilities without complicating an initial system design. Future enhancements to the sensor/tool suite are anticipated, however, initial design efforts must emphasize simplicity and reliability. Operational experience with such a system will define and justify future changes. Within the constraints imposed on this system it is possible to consider some generic tasks which may well be addressed by an autonomous system.

Sensor Driven Search/Survey

There is much interest in the small scale spatial patterns of plants and animals if we are to understand the fundamentals of ocean productivity. Also of concern to chemical and physical oceanographers is the question of discontinuities and three dimensional gradients. This time-varying data is estimated only poorly by scattered vertical casts. It is possible to consider an untethered vehicle mapping such parameters in three dimensional space using on board sensors to determine its search. As the parameter of interest decreases along a specific path, a decision would be made to follow a different path which, from on board sensor data, is determined to be within the volume containing the parameter of interest.

Long term bottom monitoring

Without a tether it is possible to direct a submersible to a specific location on the bottom. Once at that location it would be possible to turn off the power consuming system components in order to become a long term, precisely positioned, instrument package.

Midwater studies

Again, due to the lack of a tether it is possible to maintain a relatively stable position in midwater, offering opportunities for midwater observation and sampling.

Visual Inspection

Much work recently has led to the ability to transmit video images through an acoustic telemetry link. This technology allows an untethered vehicle to be used as an observation tool. Although a normal TV picture (30 frames/sec) will not be available, it is possible to obtain reasonably real-time TV pictures (4 frames/sec) from an acoustic telemetry link.

Instrument recovery, implantment, maintenance

The man-years of wasted effort and loss of much desired data due to lost instruments are devastating to a program's goals. An untethered vehicle with its accurate maneuvering capability (unhampered by tether drag forces) could home in on a mooring (instrumented with a simple beacon) and aid in instrument recovery. Some estimates place the cost of instruments lost in a single year above the cost for development of an untethered vehicle.

These tasks are meant only as a sample of the uses for an untethered system. They are certainly not meant to be all inclusive, however, they do help to bound the conceptual design of two versions of an untethered vehicle which supports ocean science.

An untethered unmanned submersible for ocean science

The following system characteristics are being considered as a conceptual starting point for a vehicle system.

Vehicle -- open space-frame structure (crab-like)

Weight -- approximately 1000 lbs.

Characteristic dimensions -- 3-4 ft

Duration -- 10 hours

Navigation -- $\pm 4''$ over 500' range, $\pm 1-3m$ over 5 km

Sensors/tools:

- . acoustically transmitted video
- . 35 mm camera remotely or automatically controlled
- . simple tool (1-2 function claw)

Major system components:

- . shipboard control station
- . dockside support van
- . vehicle system

The driving purpose for considering an untethered system lies with its potentially low cost, its ease of handling and limited burden placed on the supporting vessel. The extraordinary advances in subminiature computers, in practical applications of artificial intelligence, and the improvements in the acoustic link, open substantial potential for achieving relatively sophisticated missions. This technology, though in its infancy, shows potentially wide application as a tool for the ocean science community.

THE MONITOR NATIONAL MARINE SANCTUARY - IN PERSPECTIVE¹

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ABSTRACT

Experience gained in the management of the MONITOR National Marine Sanctuary has assisted the Sanctuary Programs Division of the National Oceanic and Atmospheric Administration (NOAA) in development of a Management model that recognizes historic shipwrecks as an irreplaceable and non-renewable marine resource.

Building upon the data base of previous ship recovery projects, and similar to the framework used for other fragile "living" marine resources such as coral reefs and fish habitats, the model focuses on the decision making process that emphasizes a balance between the protection and wise use of the resource for the maximum benefit of the American public.

INTRODUCTION

The announcement in 1974 that the wreck site of the USS MONITOR had finally been located some sixteen miles south-southeast of Cape Hatteras, North Carolina concluded more than 25 years of intrigue surrounding the whereabouts of the famous ironclad. Due to the MONITOR's legendary engagement with the MERRIMACK (CSS VIRGINIA) in the first battle between ironclad warships during the American Civil War, and it's subsequent loss in the "Graveyard of the Atlantic" a short while afterwards, the discovery of the wreck was generally regarded as some sort of "prize" by the various search groups looking for it. In 1953, The U.S. Navy had formally abandoned the vessel, relinquishing all claims to the wreck so as not to impede private interests in the search and eventual salvage of the vessel should the wreck be located (Fogler, 1953). As a result, numerous competing groups sought to locate the ironclad in what the Navy Supervisor of Salvage referred to as the "Great MONITOR Sweepstakes" (Searle, 1968).

It should not have been surprising, therefore, that the relentless enthusiasm for the MONITOR spilled over into the ensuing intense and sometimes heated debate over what would be done with the wreck now that it had been found. The arguments spanned a spectrum from those calling for immediate recovery by some eager to assert their "salvage" claim, to those calling for the wreck to be left undisturbed in the natural environment.

1. NOAA Management Rep. Series, July 1984.

NATIONAL MARINE SANCTUARY PROGRAM

The question of what would be done with the wreck, and in particular the issue of the desirability of salvage, had remained moot as long as efforts to locate the wreck were unsuccessful. However, with the wreck's discovery, the natural shroud of protection had been stripped away and an immediate concern arose as to the best method to protect it from relic hunters and disjointed recovery efforts.

Soon after discovery, a meeting in Washington, D.C. (Department of the Interior, 13 May 1974) between concerned government agencies and universities determined that due to the site location 16 miles S.S.E. of Cape Hatteras, it was beyond the jurisdiction of the State of North Carolina and that other existent federal laws did not adequately protect the site. The need for such protection was dramatically underscored by a press report of a dredging incident in an attempt to recover artifacts that same month (Ringle, 1974).

As a result, it was the consensus that provisions under a newly established law, Title III of the Marine Protection, Research, and Sanctuaries Act of 1972 afforded the best protection for the wreck. Subsequently, the site was nominated by the Governor of North Carolina and after a process of review and public hearings, was designated as the nation's first marine sanctuary by the Secretary of Commerce on January 30, 1975, the 113th anniversary of the vessel's launching.

Title III of the Marine Protection, Research and Sanctuaries Act of 1972 authorizes the Secretary of Commerce, with Presidential approval, to designate ocean waters from the shoreline to the edge of the continental shelf, including the Great Lakes, as marine sanctuaries for the purpose of preserving their distinctive conservation, recreational, ecological, cultural, and esthetic values. This was interpreted to include historic or cultural remains of widespread public interest such as the MONITOR. The National Marine Sanctuary Program is managed by the Sanctuary Programs Division of the National Oceanic and Atmospheric Administration (NOAA).

The mission of the program is to establish a system of national marine sanctuaries based on the identification, designation, and comprehensive management of special marine areas for the long-term benefit and enjoyment of the public.

The overall goals of the National Marine Sanctuary Program are to:

1. Enhance resource protection through the implementation of a comprehensive, long-term management plan tailored to the specific resources.

2. Promote and coordinate research to expand scientific knowledge of significant marine resources and improve management decision making.

3. Enhance public awareness, understanding, and wise use of the marine environment through public interpretive and recreational programs.

4. Provide for maximum compatible public and private use (NOAA, 1982A,B).

The program ensures a balanced and comprehensive approach to the protection and wise use of selected marine areas. The program is not limited to regulating particular marine-related activities or protecting singular resources, but includes non-regulatory provisions for identifying and comprehensively managing marine areas based on their various resource and human use qualities. The focus is on developing coordinated research programs to evaluate and monitor the overall condition of the resources and to assess the cumulative impacts of all activities affecting them. The program also provides an educational and informational service to increase public awareness and understanding of the value and importance of marine resources (General Accounting Office, 1981).

The program represents an innovative approach to ocean management; one based on planning, analysis, and decision making that promotes multiple use of resources while offering protection by recognizing the interplay of human activities and the natural environment. When conflicts are identified between conservation and resource use, a management strategy is developed that assures a decision that produces the maximum social benefit.

For nearly 100 years the United States has recognized the importance of special areas of its public lands. Yet these efforts have been directed almost exclusively to terrestrial areas above the high water mark of the oceans and Great Lakes, largely ignoring the more than 43 percent of the nation's public lands which lie offshore (Blumm and Blumstien, 1978).

The Program represents a mechanism for reversing this "out-of-sight, out-of-mind" attitude toward the marine environment and for actively promoting marine resource management. It provides a means to protect marine resources and promote comprehensive management in a manner similar to that used for our land-based resources. From the standpoint of resource protection, public use, and public awareness, the program mission offers a corollary to well-established terrestrial programs in that special marine areas are managed for public use and benefit in concert with resource protection (NOAA, 1982A). The protection of a historic shipwreck within the same general management framework used for other fragile, "living" marine resources such as coral reefs and fish habitats provides a sound scientific basis for learning how to treat this important, yet little understood, marine resource.

HISTORIC SHIPWRECKS AS MARINE RESOURCES

Throughout history, the ship has traditionally been one of the largest and most complex machines produced by man. As such, the ship and its contents present a discernable "finger print" of the society that produced it and can reveal a great deal of information about the people who constructed it.

A ship is built for a specific purpose at a distinct point in time. The ship and its contents were specifically selected for a narrowly defined purpose and designed to be self-sufficient and to maintain a shipboard community for extended periods of time (Lenihan, 1983). The decisions made by the builders with regard to the design, selection of materials, and method of construction paints an accurate picture of their technology and industry, while

the ship's contents reveal a great deal about their economy, society, and culture.

Normally, this transient record is dispersed at the end of the last voyage when the cargo is sold, the crew returns to their homes, and the ship is eventually broken up. It is only with the event of a shipwreck that the whole unit - ship, cargo, and shipboard community - is deposited on the seafloor, creating a material record that is archaeologically recoverable (Muckelroy, 1978).

The value of the archaeological record is that it is a more direct source of evidence about a specific ship than any other form of historical data. While it is subject to the interpretations of the archaeologist, other sources such as the documentary or the pictorial are subject to two such filters, that of the contemporary recorder and that of the modern interpreter. The fact that the deposition was totally accidental and unintentional increases the significance in that the remains show what actually existed, rather than what was thought to be there, or should have been there at a somewhat random point in time (Muckelroy, 1978). The study of a shipwreck provides an invaluable opportunity from several disciplinary perspectives to study the physical remains of man's activities on the sea, in many instances, remarkably well preserved and relatively undisturbed by the marine environment.

The scope of the science of marine archaeology is inherently linked to the potential and to the limitations of the marine environment, both as a medium for the preservation of remains, and as the physical setting in which fieldwork is undertaken (Muckelroy, 1978).

The potential for the preservation of material beneath marine sediments was recognized as early as 1832 when Charles Lyell, a pioneer in geology, concluded that "it is probable that a greater number of monuments to the skill and industry of man will in the course of the ages be collected together in the bed of the ocean, than will exist at any one time on the surface of the Continents" (Muckelroy, 1978).

The physical limitations posed by the marine environment are directly related to man's development of the necessary technology for its exploration, beginning with the invention of SCUBA in 1942, and the development of the proper tools and methodology to conduct archaeology at depth, beginning with the pioneering work of Dr. George Bass in 1960.

A historic shipwreck should be viewed as a valuable marine resource of primary source data on man's maritime activities that is not available elsewhere. The potential of this resource is restrained only by our technology and our attitudes towards its value and use. The study of this marine resource will constitute an important element in the search for a greater understanding of man's past and merits careful management to assure maximum benefit from its utilization.

An undisturbed shipwreck has been described by archaeologists as a "time capsule" containing a microcosm of historical and cultural information frozen in time at the instant the sinking occurred. The excavation of a submerged site has been likened to

"an irreversible and unrepeatable scientific experiment" that is inherently destructive of the resource and justified only with thorough documentation and reporting (Morrison, 1981). The awareness that a submerged archaeological site is an irreplaceable and non-renewable marine resource fosters the recognition that the "prize" of discovery is, in reality, a burden of responsibility to properly protect and preserve the resource and to assure it's wise use.

The act of discovery of historic shipwrecks in the past has all too often resulted in their eventual destruction. Whether this has been due to the lack of knowledge on how to deal with submerged sites or due to misplaced motivations toward some sort of "reward" for the often-times considerable effort required to locate a wreck, is of little consequence when one considers the loss of information in archaeological or historical terms.

Should excavation and the recovery of submerged material be selected as the appropriate option, then there must be a keen awareness of the extent of the responsibility to provide for the proper documentation, conservation, publication of results, and perpetual care of the artifact collection, if there is to be any lasting value to the project.

To a very large extent, the effectiveness of the conservation effort will determine how the success of the entire project is perceived. If recovery of material is undertaken, the project must be sustained through the lengthy conservation and display phases. However, if financial support wanes due to unforeseen costs or decreased public interest and the conservation is stopped due to lack of funds or inadequate technical capability, the entire project may be placed in jeopardy. There must be no hesitation in the commitment to follow through with the conservation, interpretation, final reporting, and long-term curation once excavation begins, if maximum value is to be derived from the resource.

If a ship can be described as a microcosm of a past society that produced it and warrant meticulous documentation in it's study and preservation as a shipwreck, then it is not superficial to suggest that a project to study, excavate, and possibly recover a shipwreck represents a microcosm of the society conducting it in terms of it's human values, cultural behavior, and allocation of resources and, therefore, merits equal consideration. In the final analysis, the manner in which the resource is managed and the solutions offered will determine the ultimate value of a project, and to a large extent, the quality of the endowment in cultural heritage left to succeeding generations.

Few individuals can fully appreciate the type of commitment and the level of investment in terms of time, effort, knowledge, and money often required to record, excavate, and secure the physical recovery, conservation, and long-term curation of material from underwater sites. Any project considering the recovery of an historic shipwreck should carefully study the Scandinavian experience with the WASA and the recent British experience with the MARY ROSE in comparison to the U.S. experience with the Cairo.

The WASA is a remarkably well-preserved 1628 Swedish warship recovered intact from Stockholm Harbor in 1961. This project

serves as a primary model for all other ship recovery projects. It was the first project of this type and scale ever attempted and as a result, much of the present technology for the conservation of submerged materials was developed during this project. Since there was no previous experience of the same scale with which to compare, many decisions were made without the full knowledge of what the consequences would be in terms of results or final costs. Several important lessons can be learned from this project.

First, once the decision is made to recover, there must be total commitment to conservation in terms of stable and sufficient financing. Economic factors should not be allowed to determine when the conservation process is complete. Second, an internationally significant project of this magnitude requires support from the general public as well as government institutions. Lastly, the preservation of the ship equates to perpetual care and maintenance, if the ship is to be a lasting artifact. The WASA has been undergoing conservation treatment for over 25 years (Barkman, 1978).

A more recent example is the 1545 Tudor warship MARY ROSE recovered in 1982 from 40 feet of water near Portsmouth, England. What started in 1965 as archaeological explorations to survey, record, and, if possible, identify an unknown anomaly using amateur divers turned into a seventeen year effort to completely document, excavate, and finally recover the remaining ship structure at a cost of nearly \$7 million, supported largely by private donation (Rule, 1982).

The MARY ROSE Project is a management model from the standpoint that it reveals the intricate multi-disciplinary nature of ship recovery projects that transcends normal disciplinary boundaries. The project demonstrated the essential requirement for strong management closely controlling all aspects of the project encompassing archaeology, conservation, engineering, museology, and a host of other supporting disciplines and specializations, the most important being fund raising. The highly publicized and exciting work of the discovery of artifacts and the recovery of the hull is completed. Now efforts are concentrated on sustaining the project through the lengthy conservation and display phases estimated to take another 20 years (Clark, 1983).

From the archaeological perspective, it seems unfortunate that only the relatively short, high-risk recovery phase is sufficiently spectacular to generate the crucial money and enthusiasm. In comparison, the slow toil, long-term effort, and considerable expense of adequate recording, conservation, and formal publication appear lackluster and as a result receive little public attention and, in many cases, lack the necessary planning and support (Morrison, 1981).

A lamentable example is the case of the USS CAIRO, a Civil War gunboat discovered virtually intact and well-preserved in 1956 near Vicksburg, Mississippi. The best intentions motivated by local pride, enthusiasm over the find, and lack of continuity of personnel combined to create a catastrophic loss of information and material in archaeological and historical terms (McGrath, 1981). Poor planning for the recovery resulted in the wreck being

virtually torn apart during the lifting operations. This was later compounded by the complete absence of any planning for conservation and the lack of anticipated funding to support the project (McGrath, 1981). Although the National Park Service has done an admirable job of "salvaging" what otherwise would have been a complete loss, the "Hardluck Ironclad" is a mute reminder of what can happen to an ill-conceived and hastily executed ship recovery project.

The principle danger to the surviving archaeological record, in most instances, is from excavators and salvors who in the process of uncovering material, disrupt the tenuous equilibrium between preservation and deterioration. This awareness places great emphasis on the need for planning that encompasses not only the engineering of recovery, but also the conservation, curation, and display of recovered artifact collections. It has too often been the case, that the damage in the recovery and the subsequent treatment of material has exceeded all previous damage suffered by the object during its entire existence (Peterson, 1978).

The greatest benefit from studying previous projects is that they formulate an essential data base of collective knowledge, maturing attitudes and developing experience on how to properly treat historic shipwrecks. A shipwreck should not be excavated just because it is discovered (Bass, 1978) and most certainly, recovery is not the proper answer in every case. How is this decision made? Who should be involved? What minimum standards of historical and archaeological documentation should be required? How should the projects be financed?

The MARY ROSE example clearly shows that the successful project includes many diverse elements and requires the careful cross-pollination of numerous disciplines. How the essential cooperation between various government agencies, different professionals and amateurs is elicited, and the crucial outside support is orchestrated, so that the collective "project" succeeds, is a harmonious melody that has so far eluded the United States. The difference between the CAIRO Project and the MARY ROSE Project was not a matter of luck, but rather of design through policy, management, and planning.

The National Marine Sanctuary Program is building upon the experience of past projects, hoping to provide similar elements of success for the management of the MONITOR National Marine Sanctuary, both as a suitable requiem to the "little cheesebox-on-a-raft" and to serve as a national model for the treatment of historic shipwrecks, thus adding another first to the already long list of firsts for this famous ironclad. As such, the concentration is not on the question of the recovery of the vessel per se, but on the process of arriving at the decision of what should be done with the shipwreck, recognizing that the answer to the first question lies in the understanding of the second.

MONITOR NATIONAL MARINE SANCTUARY

Since the discovery of the MONITOR in 1973 and its subsequent designation in 1975 as the nation's first National Marine Sanctuary, an abundance of conflicting viewpoints have been

expressed about the ultimate disposition of the wreck.

Due to the interaction of a great number of people, a philosophical basis has emerged on how to deal with the site. The fundamental premise is that the MONITOR is an archaeological site, and due to the ship's historical significance, and the high public interest in it, the project warrants careful and deliberate planning so that a maximum return and benefit can be derived for the American public (Smithsonian Institution, 1976). In addition to maintaining site integrity for scientific research, equal emphasis was placed on maintaining recovered artifacts, documentation, and other MONITOR-related materials intact as a single collection to be made available to researchers and the public (NOAA, 1974).

At a National Conference held in 1978, the focus was set on the fundamental question of what should be done with MONITOR, in contrast to what we can or want to do. Thus a significant emphasis was placed on the process of decision making in order to insure the maximum benefit for the American people, without degrading the historical and archaeological value of the site. This same approach was recommended for other historic shipwrecks including the USS TECUMSEH, BROWN'S FERRY, and other historic vessels whether currently known or yet to be discovered (National Conference, 1978).

Additionally, there was general consensus that more research and information about the environment and it's impact on the material condition of the wreck were necessary before any decision could be made about the ultimate disposition of the MONITOR, if it is to be treated in a scientific and technologically sound manner (National Conference, 1978).

It was recommended that the decision concerning what should be done with the MONITOR is ongoing, accompanied by a research program consisting of assessments and evaluations structured to determine the technical and fiscal feasibility of management options ranging from non-disturbance of the site to complete recovery of the wreck. The objective of research is to determine as far as technologically possible, what is fact concerning the actual condition of the wreck, to avoid decisions based on speculation.

The understanding of what is, and not what we hope or would like to be, is the fundamental issue underlying the development of any responsible and appropriate management option concerning what, if anything, should be done at the MONITOR site.

The following goals have been established for the Sanctuary:

To protect and preserve the MONITOR and all it's associated records, documents, and archaeological collections.

To insure the scientific recovery and dissemination of the historical and cultural information preserved at the MONITOR site; and to preserve and develop the physical remains of the MONITOR in a manner which appropriately enhances both the significance and interpretive potential of the vessel.

To enhance public awareness and understanding of the MONITOR as a historic and cultural resource by providing interpretive educational services and materials (NOAA, 1982A,B).

Future proposals for on-site work will be evaluated for their potential adverse impact on the resource by using the following criteria:

SUITABLE - Does the proposal support the goals of the Sanctuary?

FEASIBLE - Are the available resources adequate and do they provide assurance for the proper documentation, recovery, conservation, reporting, display, and perpetual care of any recovered artifacts?

ACCEPTABLE - Is the cost of accomplishing it worth the expected results?

Since the designation in 1975, NOAA has sponsored three major expeditions to the Sanctuary. The most extensive investigation occurred in 1979 when a team of archaeologists conducted 49 dives in 26 days from a lock-out submersible. The major accomplishment was the completion of a test excavation to collect archaeological samples and engineering data to evaluate the extent of the archaeological record and the condition of structural members buried by bottom sediments. The explorations were also history making, being the deepest archaeological excavation conducted by archaeologists to date in the United States.

The experience gained in developing the proper methodology and new techniques for working in 220 f.s.w. has been extremely rewarding in developing new approaches and tools for deep water archaeology. Additionally, the information collected by the diver/archaeologists first hand is vastly superior to the quality and quantity of other substitute remote methods currently available today.

Perhaps most germane to our understanding of the interaction of the wreck with the environment have been the results of the static equilibrium analysis. This study concluded that sections of the armor belt and adjacent exterior hull may be stressed close to their ultimate strength, and have already shown indications of plastic yielding (Muga, 1982).

A corollary study that compiled and analyzed what is presently known about the effects of the environment on the rate of deterioration concluded that the MONITOR is continuing to deteriorate from natural galvanic corrosion due to it's continued exposure to the marine environment. Unlike other historic shipwrecks that have been well-preserved due to a protective covering of marine sediments, the MONITOR (Figure 1) has, in all likelihood, been exposed most of it's history as a shipwreck to an environment characterized as highly corrosive due to the temperature, oxygen content, and current velocity (Miller, 1984).

This dynamic type of environment, as opposed to one that is static and anoxic and therefore conducive to preservation of materials, adversely affects the structural fabric due to two

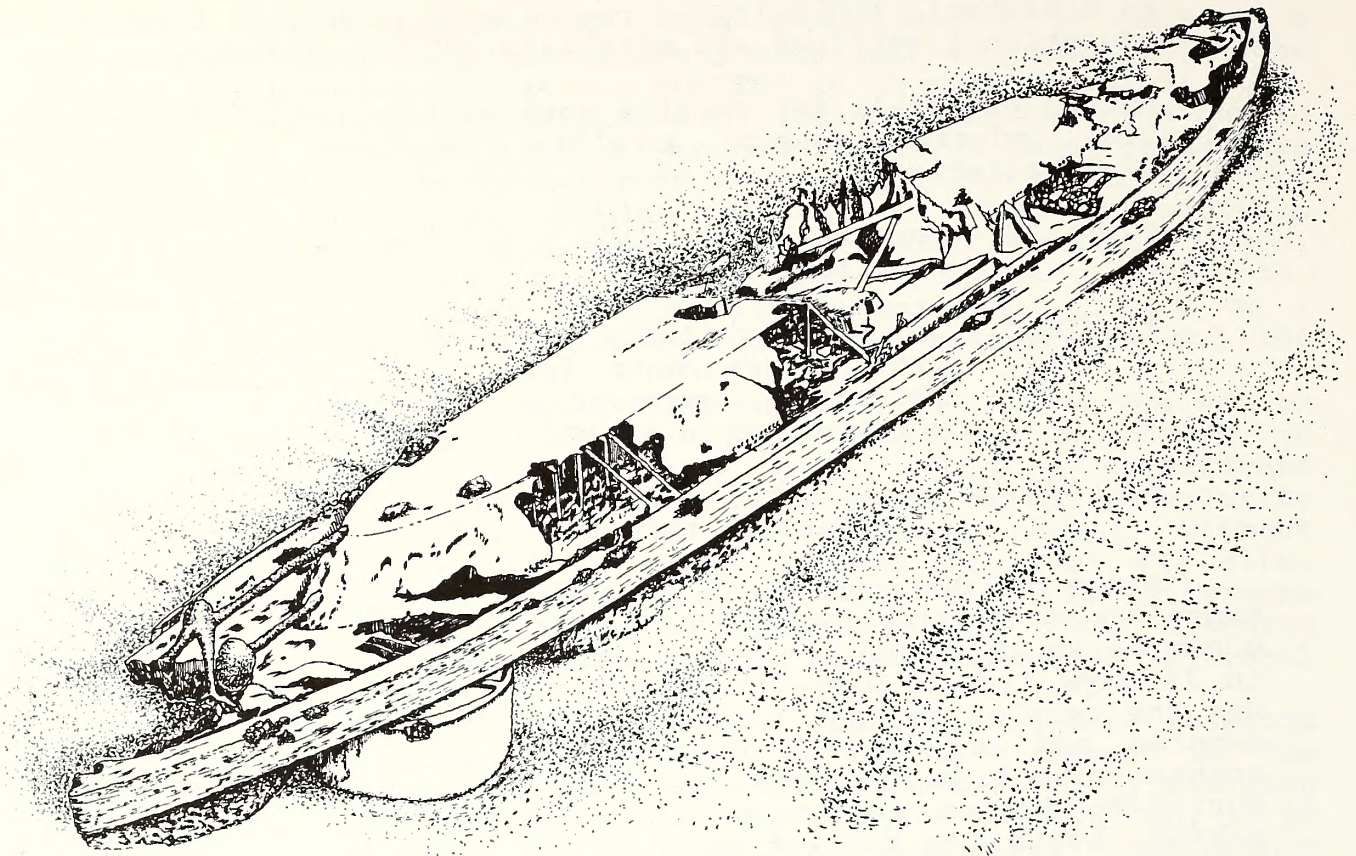


Figure 1. The hull of the MONITOR lies inverted and resting upon the displaced turret, placing severe stress on the major longitudinal support member, the port armor belt.

primary mechanisms. The relatively high velocity bottom currents transport abrasive bottom sediments which effectively erode the protective encrustation built-up by corrosion by-products that normally tend to gradually decrease deterioration over time. As a consequence, exposed material surfaces have received less protection from the insulating effect of corrosion by-products than would be expected compared to other sites.

This adverse mechanism is compounded by the continuous flow of relatively warm, highly oxygenated sea water which supplies a virtually infinite supply of ions which "feed" the corrosion reaction with the detrimental effect of accelerating the rate of corrosion of exposed material compared to similar material buried by bottom sediments. Thus, the natural environment has been a major factor in the extensive structural deterioration recorded as a result of over 120 years of submersion in sea water (Miller, 1984).

The analysis of these finding identifies a significant threat of collapse to the remaining historic structure of the vessel due to the unequal and highly stressed support provided by the displaced turret. Over one-half of the existing structure is presently being supported above the bottom by the turret (Watts,

1982). Due to the structural loadings imposed on the longitudinal members, there is a high probability that the structure will fail and collapse in the near-term (Miller, 1984).

This eventuality will adversely impact the resource by substantially increasing the rate of deterioration of the remaining ship fabric by exposing newly fractured material surfaces to the corrosive environment. Additionally, the collapse of the intact structure will seriously degrade the archaeological and historical value of the site by disrupting the engineering spaces of the ship which are a high interest/value area for future investigations (Miller, 1984).

The full impact of this threat is being further evaluated and future research efforts will attempt to refine and better quantify the measurement of residual strength and degree of strain in critical structural members. The report concludes; "The management option of 'no action' does not appear to be justifiable for the MONITOR National Marine Sanctuary as it risks the eventual loss, rather than assuring preservation, of the valuable cultural resource it was established to protect" (Miller 1984).

Whether or not any reasonable action can be taken to mitigate this threat is presently unknown. Several alternative management options are being assessed. Regardless of the outcome, however, this methodical scientific approach to the management of the resource has facilitated a quantum leap in our appreciation and understanding of a historic shipwreck as a valuable marine resource.

The management framework developed for the MONITOR provides a suitable safeguard to assure that the MONITOR question is approached in a scientifically sound manner and also provides sufficient latitude for the opportunity to develop the necessary research and management tools to preserve and properly utilize the MONITOR within the context of a management model for submerged cultural resources. The strategy to date has been successful in that the MONITOR still lies intact and protected within the Sanctuary.

Future strategies will insure decisions based, not on speculation and emotion, but on scientific method and research, building upon the existent data base on how to treat historic shipwrecks and assure the adoption of a plan that fulfills the promise of establishing a national cultural policy for historic shipwrecks in the United States.

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CHAPTER VI. DEFINITION OF
NURP-UCAP SCIENCE PROGRAM

The following outline presents the missions, objectives, and milestones of NURP-UCAP. This science program was defined during the course of several workshops and many seminar-discussions with scientists, regional coordinators, and program managers for the northern New England (Region I), southern New England (Region II) and Great Lakes (Region III) areas of the northeast during 1984, 1985, and 1986. Mission and objective inputs come from academic, government, foundation and industry participants in the NURP-UCAP program, representing 12 states, 18 universities, 5 government agencies and a commercial-recreational fishing industry valued at approximately \$5 billion annually. A major organizational and philosophical goal of NURP-UCAP is to maintain a science program that demonstrates a blend of basic and applied research that is multidisciplinary in scope and long term. A rapidly increasing portion of the NURP-UCAP science program is being directed towards experimental/process oriented research.

I. Mission - Conduct Biological, Geological, and Technical Research to Improve Living Resource (Stock) Assessment for Fisheries Conservation and Management.

- A. Objective - Evaluation, refinement, and calibration of sampling survey gear (trap, gillnet, trawl, dredge) used for stock assessment.

Milestones

1. Evaluation of gillnet fishing behavior
2. Evaluation of scallop and clam dredge behavior
3. Evaluation of otter trawl ("rock hopper" and "standard") behavior
4. Evaluation of camera sled
5. Evaluation of remote operated vehicles (ROV's)

- B. Objective - Greater information on distribution, habitat preference, abundance, migratory behavior, feeding behavior, predator-prey relationships, inter-specific competition for food and shelter, reproduction and nursery ground identification.

Milestones

1. Produce "Pictorial Atlas" on ecology, behavior, and habitat preference for western North Atlantic (continental shelf of New England, southern New England and Mid-Atlantic Bight). Summarize 25 years of research (state, federal and academic) on the northeast continental shelf.

2. Identify feeding, spawning, and nursery grounds important to survival of selected marine and fresh water species (cod, haddock, hake, herring, sea lamprey, lake trout, lobster, shrimp, etc.) including several apex predators (tuna, marine mammals).
3. Produce basic life history information on selected marine and fresh water species that cannot be studied effectively from surface research vessels. Included are in-situ depth and site specific studies directed at predator-prey relationships and inter-specific competition for food and shelter.
4. Water column ecology - identification of pelagic fauna characteristic of water masses, vertical migrations, predation on fish eggs and larvae, delivery of organics to the benthic boundary layer, mechanisms of survival and reproduction, etc.
5. Identify environmental factors governing shellfish (quahog, surf clam, scallop, lobster) recruitment (survival, growth), with the initial emphasis directed towards the coastal and estuarine environments.

C. Objective - Improve monitoring techniques which measure the response of marine organisms and ecosystems to stress, natural and man-made.

Milestones

1. Improve capability to revisit site specific monitoring stations with manned and unmanned dive systems on a time series basis.
2. Improve quantitative techniques for assessing faunal abundance - sampling and photographic documentation (i.e. acoustic imaging, laser scaling).

II. Mission - Conduct In-Situ Studies to Understand Ecosystem (Marine and Fresh Water) Response to Stress, Natural and Man-Made.

- A. Objective - Determine present status (geologically, chemically and biologically) of pre-selected fishery habitats (Great Lakes, fishing banks, basins, submarine canyons, Long Island Sound, etc.), including designated disposal, mining and oil/gas exploration sites.
- B. Objective - Identify population and community norms (behavioral, ecological, physiological, morphological) that are indicative of the well-being of living marine resources indigenous to these pre-selected habitats.
- C. Objective - Conduct in-situ, site specific monitoring of selected fauna and habitats, that are impossible to study undisturbed, from surface vessels, in response to disposal, mining, oil/gas exploration and habitat enhancement (artificial reefs) activities.

- D. Objective - Assess the fishing behavior of fixed (trap, gillnet) and mobile (trawl, dredge) fishing gear and assess their impact on ocean floor fauna and habitats, including "ghost" fishing gear. Special emphasis will be given to the impact of mobile (dredge, trawl) gear on inshore hard bottom (rocky) habitats, important as nursery and juvenile habitats for lobster and other economically valuable species.

III. Mission - Conduct In-Situ Studies to Understand the Ecological/Environmental Factors Responsible for High Productivity on Hard and Soft Substrates in the Gulf of Maine, Selected Estuarine Environments and the Great Lakes

- A. Objective - Determine patterns in the distribution and abundance of benthic/epibenthic organisms.

Milestones

1. Conduct quantitative surveys, in pre-selected locations of benthic-epibenthic organisms to define community dominance, species diversity, and abundance in large (fishing banks, knolls, coastal estuarine habitats) and small (ledge, boulder field, mud patch, etc.) scale areas.
2. Relate the above to geological features, substrate type and oceanographic/limnological conditions.

- B. Objective - Define processes important to determining the observed biotic (flora and fauna) patterns, involving experimental manipulations and high resolution time-series monitoring.

Milestones

1. Conduct in situ experiments on the effects of sedimentation, chemistry, and currents on biotic patterns.
2. Conduct in situ experiments on the rate of organic delivery to the "benthic boundary layer" versus consumption by organisms.
3. Assess the distribution of functional groups of organisms based on feeding types (suspension feeders, surface deposit feeders, and macrophagous feeders).
4. Study in situ the interactions between organisms, such as predation, or competition for food and space.
5. Define "food webs" in the benthic-epibenthic communities.

- C. Objective - Determine the mechanisms affecting benthic-epibenthic processes. The focus (milestones) of this objective will be determined by the results of the above surveys and experiments.

Milestones

1. Define energy transfer through the food web.
2. Determine nature of environment-biota interactions and how they effect various stages in the life cycle of the dominant biota in the community.

IV. Mission - Conduct In Situ Studies of the Geological and Sedimentary Features on the Ocean Floor and Great Lakes Bottom and the Processes That Shape These Environments.

- A. Objective - Assess and quantify dynamic sediment transport mechanisms which alter habitat, including the mechanisms of sediment erosion and deposition, and the effects of current patterns and water masses on sediment transport.

Milestones

1. Study in situ the effects of bioturbation (bio-erosion) on seafloor and lake floor sediments.
2. Study in situ sediment transport mechanisms, i.e. - current patterns, water masses, and the pathways of sediment-bound pollutants/contaminants.
3. Study in situ erosion of submarine canyon, upper slope and shelf environments.
4. Define distribution patterns for various sediments and their load of trace metals.

- B. Objective - Evaluate suitability of pre-selected seafloor sites for the disposal of dredge spoils and other wastes.

Milestones

1. Apply certain key criteria for designating deep ocean target disposal areas: avoid productive seafloor habitat, select containment basins and chart shape and mass balance of mound on soft-flat sediment terrain.
2. Determine mechanisms of sediment containment, chart shape and microtopographic features of mound surface, define peripheral limits and plot frontal boundary change with time.
3. Determine fishery impact effects (attraction or repulsion) at the disposal sites and long-term recolonization trends of benthic organisms.
4. Identify and monitor key indicator species for behavior response, and bio-accumulation burden of contaminants (heavy metals, hydrocarbons or PCB derivatives.).

5. Test and describe management procedures to reduce pollutant load impacts (point disposal, sequential coverage, capping and burrow pit).
- C. Objective - Investigate in situ the processes and properties associated with the fluff layer and nepheloid layer at the sediment-water interface.

Milestones

1. Implace fine-scale instrumentation (i.e. cycloidal current meter arrays) in precise locations to determine hydrodynamic forces producing geological seafloor structures (i.e. furrow fields, ripple zones, sand dunes).
2. Quantify the mechanisms responsible for benthic flux of biochemically active compounds (i.e. nutrients, C, N, P) and trace metals across the benthic boundary layer.
3. Document gradients of sediment fabric and biogeochemical state by sediment profile photography (REMOTS system) and computer image analysis.
4. Determine turnover rates of surficial sediments by in situ tracer and x-radiography experiments.

V. Mission - Provide "Ocean Services" Assistance to State, Federal and Academic Research Institutions.

- A. Objective - Support research activities designed to establish, survey, and assess potential and existing marine sanctuaries within the U.S. Extended Economic Zone, including qualitative and quantitative surveys of the biota and habitat types.
- B. Objective - Calibrate, groundtruth, and evaluate remote sensing instruments (side scan sonar, high resolution bathymetry).
- C. Objective - Provide on-site training of marine and fresh water scientists (including students) in the use of manned and unmanned diving systems and their complement of sensing, sampling, and photographic devices.
- D. Objective - Conduct technical sessions with ROV research and development engineering groups to provide biological/oceanographic recommendations for priority tasks and specific designs to achieve the maximum performance potential of "low cost" ROV systems (e.g. Mini-Rover, Sea Rover, Super Phantom). Field test fisheries/pollution/monitoring capabilities of a range of new generation ROV systems currently available to support undersea research. Continue to interact with principal submersible/ROV contractors in the design and perfection of innovative scientific devices to accomplish a greater range of in

situ tasks (i.e. parallel laser beam scaling system, nepheloid-fluff layer sampler, box and punch cores, cages, electrosampler, plankton-suction sampler).

VI. Mission - Conduct Biological and Geological Studies In-Situ on the Environmental Mechanisms Affecting the Survival and Growth of Selected Species Targeted for Agriculture.

- A. Objective - Determine the effect of increasing east-to-west Long Island Sound nutrient/phytoplankton and pollution gradients on recruitment and growth of a prime shellfish species (Mercenaria).
- B. Objective - Evaluate, by in situ methods, the environmental influences on growth and survival of post set clams (water quality, predation, substrate, density dependence) at eight geographically spaced stations throughout Long Island Sound.

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